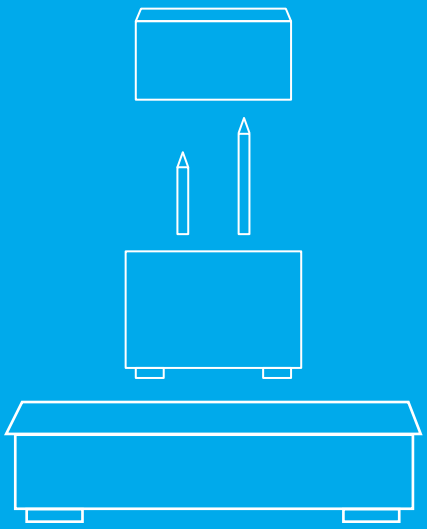
User Manual

HYPROP



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1 HYPROP system

Laboratory evaporation method according to WIND/SCHINDLER for the determination of unsaturated hydraulic conductivity and water retention characteristics of soil samples.

1.1 Safety instructions and warnings

Electrical installations must comply with the safety and EMC requirements of the country in which the system is to be used.
Please note that any damages caused by users are not covered by warranty.
Tensiometers are instruments for measuring the soil water tension, soil water pressure and soil temperature and are designed for this purpose only.

Please be aware of the following warnings:

- High pressure: The maximum non destructive pressure is 300 kPa = 3 bar = 3000 hPa. Higher pressure, which might occur for example during insertion in wet clayey soils or during refilling and reassembling, will damage the pressure transducer!

- Ceramic cup: Do not touch the cup with your fingers. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.

- Freezing: Tensiometers are filled with water and therefore are sensitive to freezing! Protect Tensiometers from freezing at any time. Never leave Tensiometers over night inside a cabin or car when freezing temperatures might occur!

- Do not use a sharp tool for cleaning the threads in the sensor unit. Just rinse it with pure water from a spray bottle.

1.2 Content of delivery

The delivery includes two bags and the package incl EG2200 Scale:

Bag 1: (black lock, similar for each HYPROP-E) is consisting of (Figure 1-1) :

- Sensor unit, set of Tensiometer shafts, 2 each 50 / 25 mm
- acrylic attachment for sensor unit (3) Perforated saturation bowl (4)
- HYPROP connecting cable (5), 6 pcs. filter fabric, 15 cm x 15 cm (6), Silicone gasket (6)
- tensioLINK® T-piece junction plug(7) and silicone prot. caps (8)

Figure 1-1

Bag 2 (white lock): service kit, which includes (Figure 1-2):

- Bottle of deionised water (1)
- Syringes incl: 2 reservoir syringes (2), - 2 vacuum syringes (with red O-ring at tip) (3) 1 vacuum syringe with acrylic attachment (4) incl. tube (12) and 1 droplet syringe (5)
- Sampling ring with 2 plastic caps* (6)
- Tensiometer auger (7) and auger adapter (11)
- Cable set consisting of: Mains power device* (9), HYPROP USB- converter (10)
- tensioVIEW® software on CD

Figure 1-2

1.3 Expression of thanks

Dr. Uwe Schindler was able to considerably simplify the evaporation method by WIND by analyzing the evaporation process and the spatiotemporal decrease of water content inside the sample during the evaporation process. The results of surveys of more than 2000 samples became part of German and international soil data bases (HYPRES, UNSODA) and were basis of many scientific studies.
List of referring publications:

1. Schindler, U. (1980): Ein Schnellverfahren zur Messung der Wasserleitfähigkeit im teilgesättigten Boden an Stechzylinderproben. Arch. Acker- u. Pflanzenbau u. Bodenkd., Berlin 24, 1, 1-7.
2. Schindler, U.; Bohne, K. and R. Sauerbrey (1985): Comparison of different measuring and calculating methods to quantify the hydraulic conductivity of unsaturated soil. Z. Pflanzenernähr. Bodenkd., 148, 607-617.
3. Schindler U., Thiere, J., Steidl, J. und L. Müller (2004): Bodenhydrologische Kennwerte heterogener Flächeneinheiten-Methodik der Ableitung und Anwendungsbeispiel für Nordostdeutschland. Fachbeitrag des Landesumweltamtes. H.87. Bodenschutz 2. Landesumweltamt Brandenburg. Potsdam. 55 S. http://www.brandenburg.de/cms/media.php/2320/lua_bd87.pdf
4. Schindler, U., Müller L. 2006. Simplifying the evaporation method for quantifying soil hydraulic properties. J. of Plant Nutrition and Soil Science. 169 (5). 169.623-629.

Mr. Andre Peters, in his dissertation at the Institute for Geoecology of the Technical University Braunschweig, headed by Prof. Dr. Wolfgang Durner, has scientifically examined the theoretical principles of the calculation method and improved the method to be more precise. Furthermore, he developed the software SHYPFIT 2.0 to adapt the retention and conductivity functions to the measured data, and implemented it in the HYPROP calculation software.
The thesis is documented in following publications:

1. Peters, A., and W. Durner (2008): Simplified Evaporation Method for Determining Soil Hydraulic Properties. Journal of Hydrology, under review.

2. Peters, A., and W. Durner (2007): Optimierung eines einfachen Verdunstungsverfahrens zur Bestimmung bodenhydraulischer Eigenschaften, Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, im Druck.
3. Peters, A., and W. Durner (2006a): Improved estimation of soil water retention characteristics from hydrostatic column experiments, Water Resource. Res., 42, W11401, doi:10.1029/2006WR004952.
4. Peters, A. und W. Durner (2006b), SHYPFIT 2.0 Users Manual, Internal Report. Institut für Geoökologie, Technische Universität Braunschweig.
5. Peters, A., and W. Durner (2005): Verbesserte Methode zur Bestimmung der Retentionsfunktion aus statischen Säulenexperimenten, Mitteilungen der Deutschen Bodenkundlichen Gesellschaft. 107, 83-84.
6. Peters, A., and W. Durner (2007): Optimierung eines einfachen Verdunstungsverfahrens zur Bestimmung bodenhydraulischer Eigenschaften, Tagung der Deutschen Bodenkundlichen Gesellschaft, Dresden, 2-.9.September 2007. URL: http://www.soil.tu-bs.de/pubs/poster/2007.Peters.Poster.DBG.pdf .

Sincere thanks are given to them for their support in the development and for the numerous theoretical discussions and practical advice. This helped to turn the method into a reliable system with both, high accuracy and repeatability and excellent user friendliness.
The technical and scientific high-lights of the HYPROP system are the interactive graphical menu, the automatic offset correction and the fitting routines according to Peters and Durner (2006b). Thus, your HYPROP system is an extraordinary high tech soil laboratory system.

1.4 Intended use

The intended use of the HYPROP system is the measurement and determination of water retention characteristics and unsaturated hydraulic conductivity as a function of water tension or water content in a soil sample.

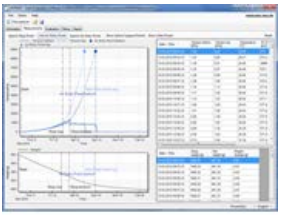
1.5 Guarantee

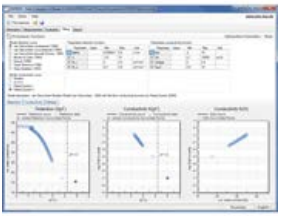
UMS gives a guarantee of 12 months against defects in manufacture or materials used. The guarantee does not cover damage through misuse or inexpert servicing or circumstances beyond our control. The guarantee includes replacement or repair and packing but excludes shipping expenses. Please contact UMS or our representative before returning equipment. Place of fulfillment is Munich, Gmunder Str. 37, Germany!

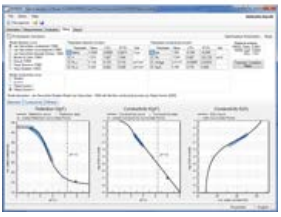
1.6 Important note

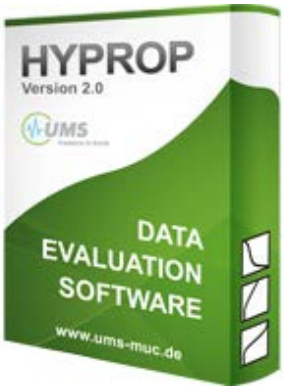
This Manual describes the hardware functions, the set-up, how to perform a measuring campaign, service and maintenance. The calculation and fitting procedure settings and background is described in a separate Manual, which will be installed with our new HYPROP-FIT Software (see attached link below)

New release of the data evaluation and hydraulic functions fitting software HYPROP-FIT.









Download Software

The new software for evaluation of HYPROP measurements can be downloaded here:

http://www.ums-muc.de/static/HYPROP-FIT.zip

2 Process summary

1. Preparation of sample and hardware
1.1. Fill HYPROP sensor unit(s) and Tensiometer shafts
1.2. Take samples with soil sampling rings
1.3. Saturate the soil samples
1.4. Drill the holes for the Tensiometer shafts
1.5. Place the sampling ring on the sensor unit
1.6. Connect the sensor unit to the PC
1.7. Connect the scale to the PC

2. Configuration of the tensioVIEW software
2.1. Add the scale
2.2. Define your measuring campaign
2.3. Select file and sample name(s)
2.4. Optionally select units and intervals
2.5. Optionally enter initial water content or select „automatically“
2.6. Select model and soil type

3. Execute the measurement campaign
3.1. Start the measurement, data is stored from this point
3.2. Wait for constant starting conditions
3.3. Set the starting line as soon as tension readings are constant
3.4. Weigh the samples in intervals, every 12 to 48 hours depending on soil type
3.5. When one of the Tensiometers runs dry make the final weighing and stop the campaign

4. Evaluation of Data with Hyprop DES
(see pdf, link on page 10)

3 Product description

3.1 System components

A measuring system can include one or several HYPROP assemblies (max. 20). A HYPROP assembly consists of a sensor unit and a sampling ring with a soil sample which is placed on each sensor unit. Sensor units are linked to a PC via the serial tensioLINK® bus.
In intervals each sensor unit with sampling ring is weighed on a laboratory scale. The scale must have either a RS232 or USB interface, and the scale type must be implemented in the software.

3.2 Sensor unit

3.2.1 Main body

The electronic components and pressure transducers are incorporated in the main body of the sensor unit. The sensor unit is splash water proof (IP65) and can be cleaned with water as long as the plug cover is closed.

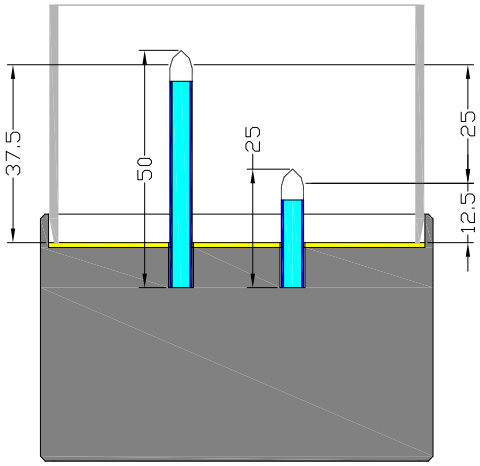


Figure 3-1

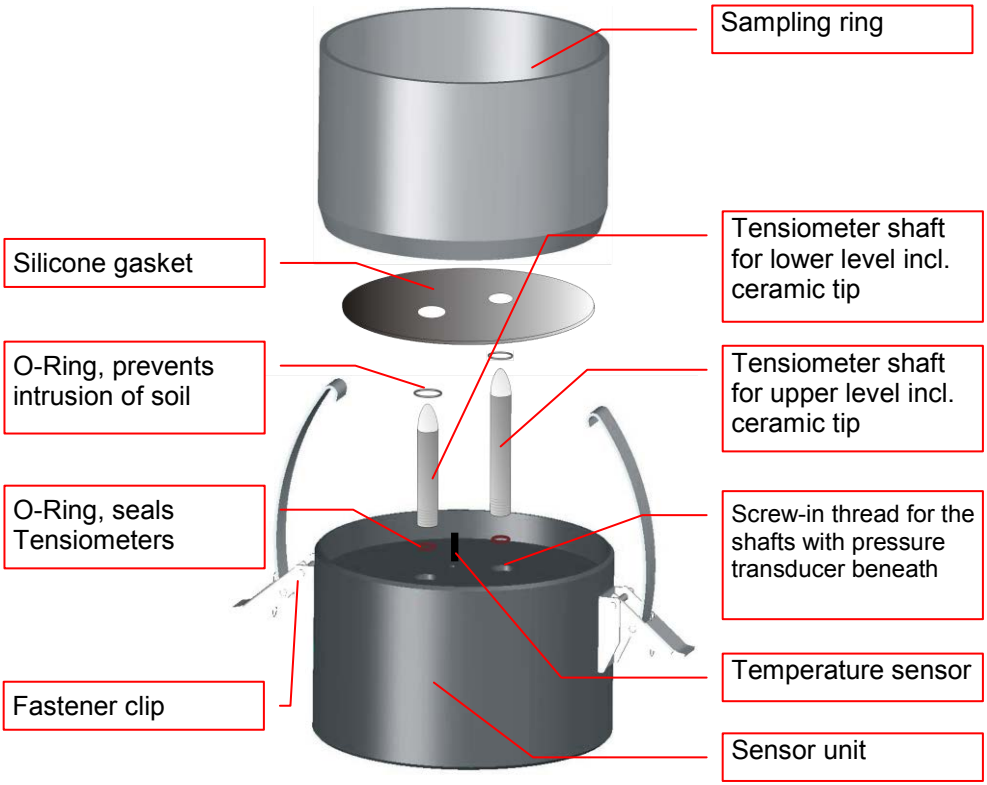

Sampling ring
Silicone gasket
Tensiometer shaft for lower level incl. ceramic tip
O-Ring, prevents intrusion of soil
Tensiometer shaft for upper level incl. ceramic tip
O-Ring, seals Tensiometers
Screw-in thread for the shafts with pressure transducer beneath
Temperature sensor
Fastener clip
Sensor unit

Figure 3-2

3.2.2 Pressure transducers

The internal pressure transducers measure the soil water tension in the sample through the two shafts differentially against atmosphere.

3.2.3 Tensiometers

Tensiometers measure the soil water tension or the matric potential.

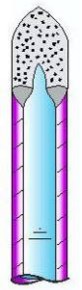


Fig 3-3

These Tensiometers have a measuring range of +100 kPa (water pressure) to -85 kPa (water tension). With proper filling the Tensiometers may work beyond the conventional tension measuring range. If the soil gets too dry the Tensiometer needs to be refilled (see chapter “Refilling”).
The soil water tension is conducted via the porous ceramic tip to the water inside the shaft and measured as an analogue signal by the pressure transducer.
The Tensiometer shafts are screwed into the transducer openings in the sensor unit. Standard sampling rings can easily be placed on the sensor unit so the Tensiometer ceramic tips are positioned inside the soil sample. There is one short and one long shaft to pick up the tension at two depths.

The Tensiometer shafts are one of the most sensitive parts of the system. Always handle them with care.

To transfer the soil water tension as a negative pressure into the Tensiometer, a semi-permeable diaphragm is required. This must have good mechanical stability and water-permeability, but also have gas impermeability.
The Tensiometer tip consists of porous ceramic Al_2O_3 sintered material. The special manufacturing process guarantees homogeneous porosity with good water conductivity and very high firmness. Compared to conventional porous ceramics the tip is much more durable.

The bubble point of a Tensiometer ceramic is about 800 kPa. If the soil gets dryer than the bubble point, air passes through. Thus, the negative pressure inside the cup decreases and the readings go down to 0 kPa.
With these characteristics this material has outstanding suitability to work as the semi permeable diaphragm for Tensiometers.

Be aware that the ceramic will dry out when it is exposed to air uncovered. Always put on the rubber cap filled with some water.

3.2.4 Temperature sensor

A temperature probe sits inside the small stainless steel pin on the sensor unit. It measures the temperature of the soil sample. Although the temperature is not part of the measurement it is useful information for reviewing the quality of a measuring campaign. The sensor has a tolerance of ±0.2 K at 10 °C.

3.2.5 Plug connector

The bus cable is connected to the plug on the side of the sensor unit.

As the plug is taken on and off regularly during a measuring campaign an easy-going push-pull plug is used.
A simple-to-open spring-loaded cover protects the plug when no cable is connected. Tightly close the plug cover before cleaning the sensor unit.

Figure 3-4

- Dirt water inside the plug opening will destroy the functionality of the connector.
- Do not twist the plug.
- Make sure that the cover is closed tightly before cleaning.

3.3 Sampling ring

A soil sample is taken with a stainless-steel sampling ring which has a volume of 250 ml. The sampling ring is placed on the sensor unit and fastened with the two clips. A silicone gasket completely seals the bottom of the soil sample.

3.4 Software tensioVIEW®

The HYPROP system is equipped with the tensioLINK® measuring bus.

Fig. 6: tensioVIEW®

With tensioLINK® you are able to create an extended network. The network is connected to a PC with the tensioLINK® USB-converter. The Windows software tensioVIEW® is used for configuration of the devices and to visualize data. The software automatically recognizes all connected devices.

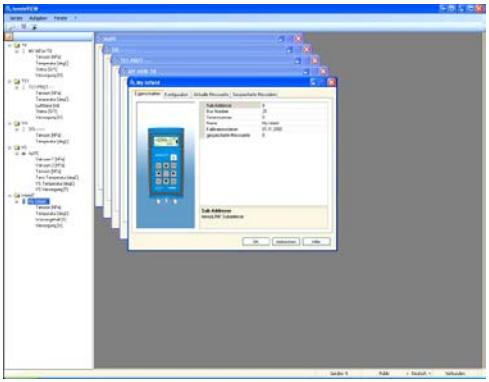


Figure 3-5

Additional functions are integrated in tensioVIEW® for optimized usage with HYPROP (see chapter ”Performing a measuring campaign“.). The functions are activated whenever the bus recognizes that a HYPROP unit is connected.
If a laboratory scale with serial RS232 or USB interface is used readings are automatically taken and evaluated by the tensioVIEW® software.

4 Get ready to start a measuring campaign

The following tools are required to prepare a HYPROP unit before a measuring campaign:

- Sampling ring, volume 250 ml
- Perforated saturation bowl
- A dish or bowl with minimum rim height 7 cm
- Mesh fabric, 15 cm x 15 cm
- Auger positioning tool
- HYPROP auger
- Pair of scissors*
- Service case for Tensiometer refilling

* not included

Figure 4-1

4.1 Soil samples

4.1.1 Soil Sampling

Samples should be as fresh as possible. Please follow the guidelines for taking soil samples (described in DIN 4021, “Exploration by excavation and borings; sampling)

Figure 4-2

Following a short instruction for soil sampling based on lecture notes from Prof. Dr. W. Durner:
Uncover the preferred soil level. This can be either vertical or horizontal. Hammer in the ring by using a proper knock-on handle and a medium size hammer. Hammer in straight and avoid tilting the ring. Carefully excavate the ring with a knife or spatula. Now cut off the overlapping soil along the ring’s rim with a very sharp knife - take care not to smear the pores. Cover the samples with protective caps for transportation. In general a minimum of 5 to 10 samples per soil level are taken to determine the bulk density and the retention curve.
Weights of the sampling rings might vary. Therefore, it is essential that the rings are specifically weighed.

4.1.2 Saturate the samples

Remove the protective cap from the upper side of the sample (the side with the straight rim without cutting edge) and place the mesh fabric on the sample.

Figure 4-3

Attach the perforated saturation attachment to clamp the cloth.
Turn around the sample and remove the second plastic cap.
Fill the dish with water and place the sample in the dish, standing on the perforated attachment.

Figure 4-4

The water level should be 2 cm in the basket. Please place the sample ring incl. saturation bowl in the basket.
The cutting edge shows upwards, thus the sample is saturated capillary from the reverse side.
After 4-6 h fill new water inside the basket ca. 1cm below the upper rim of the sampling ring.

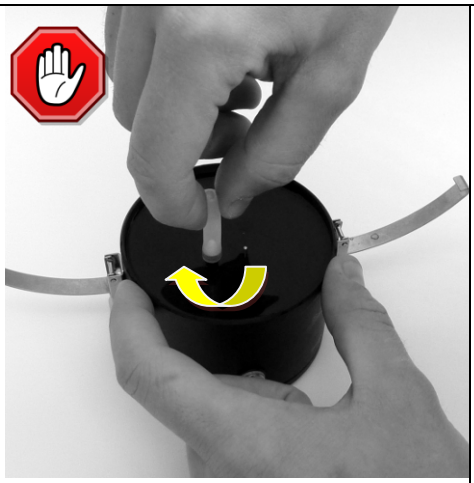
Important note: Slightly lift up and tilt the sampling ring with saturation attachment inside the water filled saturation bowl. This prevents that air bubbles are trapped between soil sample and mesh fabric. Do this carefully so no soil particles are flushed out.

The duration until the sample is saturated and all air is removed will depend on the soil type. When saturated, the sample surface will have a glossy appearance. Clayey soil will need the longest (several days).

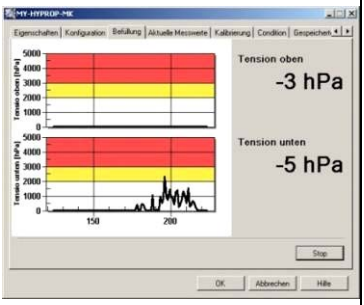
4.2 Filling

Important cautions

Caution: The Hyprop uses highly sensitive pressure transducers. Improper handling can cause irreversible damage! Read the chapter about refilling in this manual first.



Be extremely cautious when screwing in the filled Tensiometer cups. The pressure inside the cup will rise abruptly and exceedingly! Always observe the pressure in the online window of tensioVIEW!



Screw in the shaft slowly, make sure the pressure always is below the yellow range.
Read the complete chapter about refilling in this manual!

	<u>Be cautious when pulling off the tube as vacuum is inside!</u> An abrupt negative pressure change on the water column might destroy the pressure transducer. Do not pull off the tube rapidly. Allow the pressure to be released through the end of the tube or pull off the tube slowly so the pressure inside the refilling adaptor will rise slowly.
	<u>Be cautious when tapping off air bubbles!</u> Do not knock the sensor head too hard when under pressure. Any impact of the water column might destroy the pressure transducer.
	After finishing the degassing it is important to remove the tube by pressing down the blue ring on the tube connector. Do not pull out the tube with force as this might cause leakage of the connector.

Before starting and after every completed measuring campaign (the sample is dried out) the Tensiometers need to be filled or refilled bubble free with deionised and degassed water. We recommend degassing and refilling the HYPROP-Tensiometers after every completed measurement campaign. If the measurement is stopped before the bubble point of the Tensiometers are reached they can be reused, provided the ceramic is kept moist (plug on the rubber cap filled with some water).
Two spare Teniometer cups are supplied. Always keep them moist, because then the degassing and refilling will be quicker.

- Keep the ceramic moist when not in use by covering them with the water filled rubber cap.

- Ceramic tip: Do not touch the tip with your fingers. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.

- The used Vacuum pump should be able to evacuate 2 kPa closed to vacuum

The HYPROP-service kit or a vacuum system and a PC/Laptop with tensioVIEW® software are required for filling or refilling.

4.2.1 Refilling of the HYPROP

This chapter describes the refilling using a vacuum pump and manual refilling using the tools of the HYPROP service kit.

The procedure requires 4 steps, which will be discussed in detail later in the chapter:

- Degas ceramic cup and shaft
- Degas the sensor unit
- Reassemble
- Check the result

4.2.2 Degas ceramic tip and refill HYPROP shaft

If the tip is completely dry just put the empty shaft in a beaker with de-ionized or distilled water (1,5 cm level) and leave it overnight.

Figure 4-5

HYPROP shafts should never be filled from the inside. To avoid that air is trapped inside the ceramic the water must flow in one direction only from the outside into the interior.

Keep parts clean so there will be no leaking when vacuum is applied.

Refilling with a Vacuum pump:
Connect rubber tubes to the shafts. Connect the tubes to a vacuum bottle, and the vacuum bottle to the pump.
Start the pump and evacuate the system for at least 30 minutes and switch off the pump for 1h. The vacuum drops down slowly, air bubbles become smaller and can ascend. Repeat this procedure approximately three times. When water (circa 10 ml) was drawn through both ceramic tips they are filled.

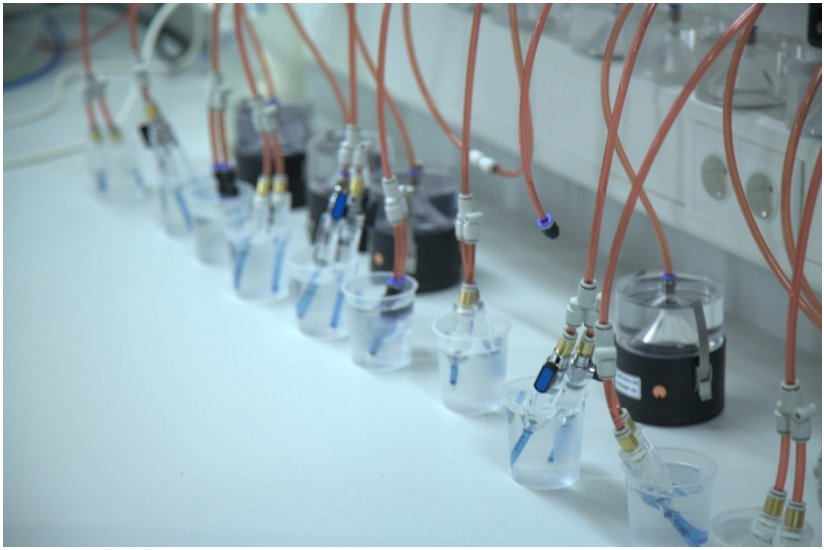


Figure 4-6

Manually Refilling (incl. delivery):
Alternatively, take the reservoir syringe, fill it with completely degassed water[1] and take care to avoid bubbles in front of the ceramic. Fill the shaft with water and plug the vacuum syringe filled with ¼ deionized degased water completely over the thread. Pull it, until both snappers are locked. Now, the water from the reservoir syringe is drawn through the ceramic tip into the vacuum syringe. When approximately 10 ml are flushed through the ceramic the HYPROP shaft is filled.

Figure 4-7

[1] Push out all air from the syringe. Now plug the end of the tube with your finger and pull up the syringe. This creates vacuum inside the syringe and dissolved gas is released. Rotate the still evacuated syringe to collect all bubbles from the wall of the syringe. Hold the syringe upright and slide in the piston. Unblock the tube and push out all air. Repeat this procedure until no bubbles are produced anymore.

4.2.3 Degas the sensor head

- Avoid that the plug connector gets in contact with water.
- Take care that the piston never recoils abruptly as this might damage the pressure transducer (max. 3 bar)!

Please note: new vent cock assembled to the acrylic attachement of the sensor head .
Figure 4-4 vent cock vertically: closed to ambient air
Figure 4-5 vent cock horizontally: open to ambient air, ventilation of the sensorhead, but closed to vacuum pump.

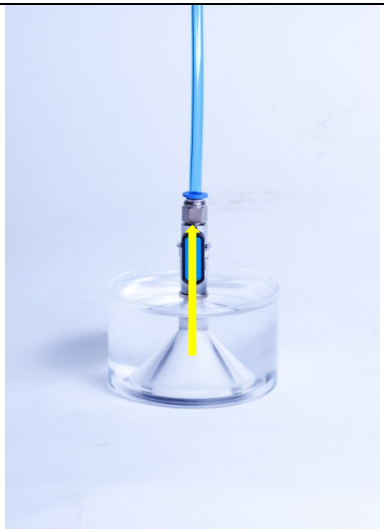


Figure 4-8

Figure 4-9

Please fill the two threads with degased water carefully with the droplet syringe

Figure 4-10

and fill up the bottom of the sensor head until the upper edge.

Figure 4-11

Filling with vacuum pump:
Place the acrylic sensor head attachment onto the sensor head. The sensor head should sit firmly on the O-Ring. Fill up the acrylic attachment with deionised water using the droplet syringe up to 1 cm above the upper edge of the sensor head and connect the tube to the acrylic sensor head attachement and the vacuum pump.
It is important to know that the vacuum is not applied abruptly. This can be done very easily with the vent cock. (from open position (Figure 4-9) to closed position (Figure 4-8))

Manually Refilling:
Take the syringe that belongs to the sensor unit attachment. Draw up 15 ml of water.

Figure 4-12

Degas the water as described before and push out all air from the syringe.
Place the acrylic sensor head attachment onto the sensor head. The sensor head should sit firmly on the O-Ring. Fill up the acrylic attachment with deionised water using the droplet syringe completelly full. (see Fig. 4-8).
Fill the tube with water.
Attach the tube, the vacuum syringe and the acrylic attachement
Draw the syringe up until the black spacer snaps in. Air bubbles will assemble inside the syringe. To avoid damaging the pressure transducer, please securely hold the piston so it will not suddenly recoil. Release the spacers and allow the piston to return slowly. Only water should flow back into the acrylic attachment. Take off the tube and push the assembled air out of the syringe. Reattach the tube and draw the syringe up again until the spacers snap in (repeat this procedure 3 times. The water now is being degassed.)
We recommend controlling the quality of the vacuum by observing the refilling window in tensioVIEW

4.2.4 Reassemble the sensor unit

- When screwing in the Tensiometer shaft into the thread of the sensor head it is very important to monitor the pressure in the refilling window in tensioVIEW®.
- The pressure sensor diaphragm is inside the small hole (ca. ∅2 mm) on the pressure sensor unit. It is very sensitive and must never be touched! It can be destroyed even by slightest contact (e. g. with a needle).
- No contamination should get on sealing and gasket.

Please connect the HYPROP cable and the USB cable to the sensorhead and start the refilling window in tensioVIEW®. The pressure signal should be very closed to zero.
Push the silicone cap (or tube) over the shafts to protect the ceramic, please don´t touch the ceramic with your fingers!
Add a drop of water on top of the shaft with the droplet syringe, so the meniscus is convex (see Figure 4-9)
Each hole on the sensor unit is marked by a groove. The long shaft is inserted where the long groove is, and the short shaft where the short groove is.

Figure 4-13

Figure 4-14

Carefully screw the shaft into the sensor unit. While screwing (ca 8 turns) in the Tensiometer shaft the pressure must not exceed 1 bar (burst pressure = 3 bar). In case the pressure rises to high, stop the turning in and wait until the pressure has dropped. You will clearly notice the point when the shaft hits the O-ring inside the sensor unit. From this point do only another quarter turn!

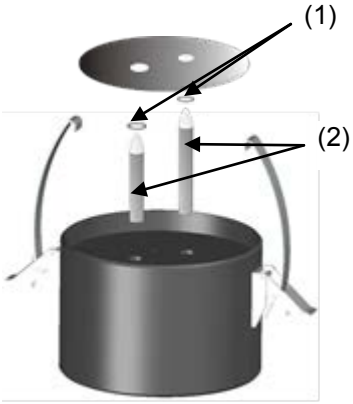


Figure 4-15

On the sensor unit push an O-ring (1) over each of the shafts (2) to the very bottom. The rings will keep out dirt once the Tensiometer shafts are installed. Place a water filled silikon tube on the ceramic tip. It is very important that the ceramic is always wet.
Repeat the same procedure with the second HYPROP shaft.

4.2.5 Check the HYPROP

Please start again the refilling window.

To check the Zero point, please put a droplet of water onto the ceramic tip. The values should be around 0 +/- 3 hPa (0,3 kPa)

Wrap a dry paper towel around one ceramic tip to create a momentary dry ceramic surface. Now create airflow around the ceramic cup, e. g. by waving a sheet of paper. The reading should rise to -800 hPa (-80 kPa) within seconds. If this is the case, the Tensiometer is filled correctly. Do the same with the second tip.

To find out the maximum measuring range of the Tensiometers take a bottle filled with water and hold the ceramic tip into the headspace of the bottle. When you move the ceramic away from the water surface the air gets dryer and the suction rises.
Hold the ceramic close to the water surface so the tension reading will rise slowly. Depending on the filling quality the value will reach -85 to -450 kPa. Then, the value will rapidly drop to the vapor pressure (around -90 kPa depending on the altitude). Now immediately put some water on the ceramic and cover the ceramic with the protective rubber cap which should be halfway filled with water. It will take one day until the Tensiometer will reach its initial value.

4.3 Attach the sampling ring

Take the saturated soil sample out of the saturation dish. Place the auger positioning tool on the sampling ring as shown in the picture..

Insert the auger into each opening and drill a hole in 3 steps (to avoid compressing the soil). Drill as far as the auger will go. Rotate the auger while pulling it out of the sample. Then, you will have 2 holes in the sample, each with the proper depth. With a pen make a mark on the side of the sampling ring where the deeper hole is (see Figure 4-12). Then you know the correct position when placing the sample on the sensor unit

Figure 4-16

To avoid that air will be pressed inside the sample it is recommended to fill up the holes with water. (see Figure 4-17). The sample now is ready for attaching the sensor unit.

Wipe off the ring surface after having drilled the holes.

Figure 4-17

- Watch your mark. The long shaft must be inserted into the deeper hole. Keep the ceramic tips wet!
- If the soil sample swelled up during saturation the overlapping soil must be cut off before attaching the sensor unit.

Remove the protetion tube from the ceramic tip. Place the silicone gasket on the bottom of the sensor head (mud protection).

Figure 4-18

Turn the sensor unit up side down and carefully place it on the soil sample by inserting the Tensiometer shafts into the drilled holes. Please take care that no air gaps and soil compression will happen.

Now turn the assembly and remove saturation bowl and cloth. Close the clips to fix sampling ring and sensor unit.

Figure 4-19

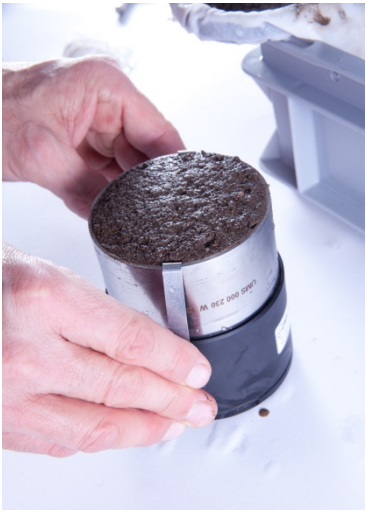


Figure 4-20

5 Set-up the HYPROP

In the next step please place the sensor head on the tared scale and plug in the cables.

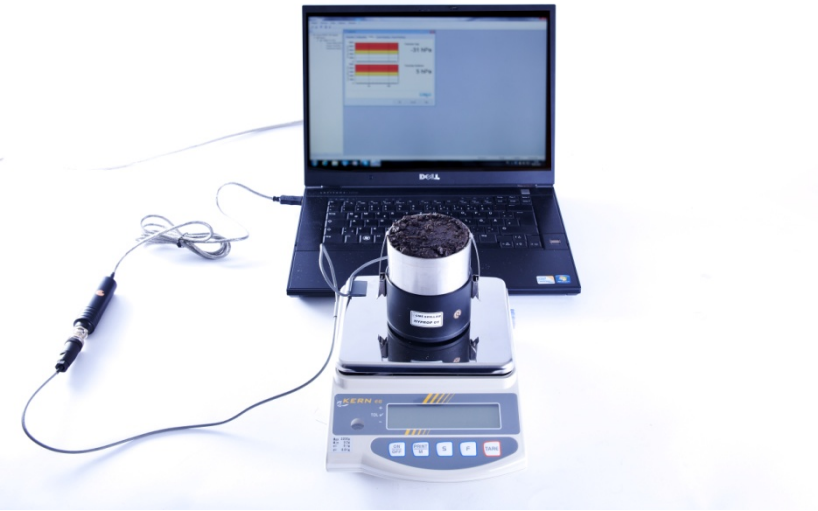


Figure 5-1

5.1 Connect the system components

The next step is to connect the components with tensioLINK®.
Up to 20 sensor units can be linked to a PC at the same time with the supplied bus cables and distributors.
Above (Figure 5-1) the sensor unit is directly connected to the PC with the HYPROP USB-converter. The internal power supply of the USB-converter is capable of powering a single sensor unit. (please be aware to set the PC to constant power mode)

Figure 5-2

In the multi device mode connect each sensor unit to a T-piece plug with a HYPROP connecting cable. Sensor units can be connected in any order as the software recognizes the position of any sensor unit automatically.

Finally connect the main power supply unit to the plug of the last T-piece plug and the HYPROP USB converter to a free USB port on your PC. The internal power supply of the USB-converter is capable of powering a single sensor unit. As soon as 2 or more sensor units are connected the USB-power supply is not sufficient. Therefore, the main power supply unit should always be connected.

In the single device mode the HYPROP assembly remains on the scale and the USB-cable is connected all the time. Therefore, it is important to stabilize the USB-cable. A proper stabilization for the USB-cable is required. Even smallest movements of the cable can cause erroneous measurements. (see more next chapter)

Figure 5-3

5.1.1 Scale

A laboratory scale with interface is required. If the type of scale is not in the following list, the scale is not supported and has to be send in to UMS (incl. manual and interface cable).

Supported scales:
Kern EG2200 (recommended)
Kern EW3000
Kern 572
CHYO MK2000B
Mettler Toledo SICS
Mettler Toledo PM2000
COBOS COBOS-CB Complet

If the scale has a serial RS232 interface connect it to a free COM-port on your PC. You can use a RS232-USB-converter if no COM-port is available on your PC. Please carefully follow the instructions for the RS232-USB-converter.

The set-up of the scale in tensioVIEW® is described in chapter 5.3 „Add the Scale“

Figure 5-4

Please note the following requirements for the operation of the scale (also see 6.1 Starting conditions p 50):

1. The scale should be placed on a vibration-free work table.
2. The work table should only be used for the HYPROP measurement.
3. The scale must be levelled out. Most scales have a bubble-level.
4. Since the Earth's gravity varies at each location the balance has to be calibrated before the initial operation and every time the balance is relocated. A periodical recalibration is recommended. Use a standard weight of accuracy class M1. Please read and follow the instructions in the manual of the balance. The recommended scale Kern EG 2200 has an internal precision weight, thus the accuracy of the balance can be checked at any time and adjusted.
5. The weight, marked on the samping rings, relates to a gravity of 9,802 ms-2. The gravity mainly depends on the latitude 9,780(0°) -9,833 (90°) ms-2.
6. Cable fixation
   To avoid errors the HYPROP cable must be fixed. Mount the HYPROP sensor cable as shown in the picture below. Clip the cable into the cable clips. The cable should be put on the scale and tared to “0”

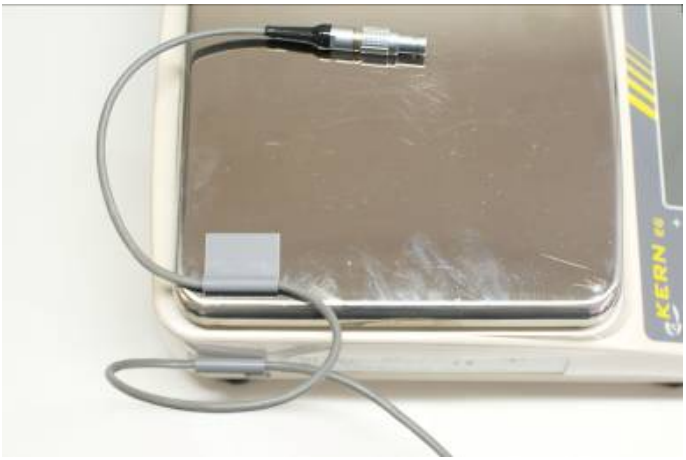


Figure 5-5

Figure 5-6

Cable length between plug and upper cable clip should be about 15 cm.
Cable length of the loop between both cable clips should be about 20 cm.

If you don´t have this clips please ask us for the accessory kit (incl Application Note) to fix the cable. It is free of charge.

5.2 Software tensioVIEW®

5.2.1 Menu

tensioVIEW® has simple, mostly self-explaining menus for read-out and configuration of tensioLINK devices.
After starting tensioVIEW® the display is more or less blank, most functions are not activated.

5.2.1.1 Find devices

If one or more sensors are connected via the USB-converter they can be found by pressing the “magnifying glass” button.

tensioVIEW® offers two options for searching:

5.2.1.2 Single device mode

tensioVIEW® expects that only one device is connected which will be found very quickly. This mode is not functional if more than one device is connected!

5.2.1.3 Multiplexed devices mode

tensioVIEW® is able to run up to 20 HYPROP sensor units connected to the bus within 8 seconds, but only if each device is already personalized with an individual bus identification address. If two or more devices have an identical address, none of them will be found.
All devices found will be displayed in the left section in a directory tree. Same types of devices will be grouped in one directory.

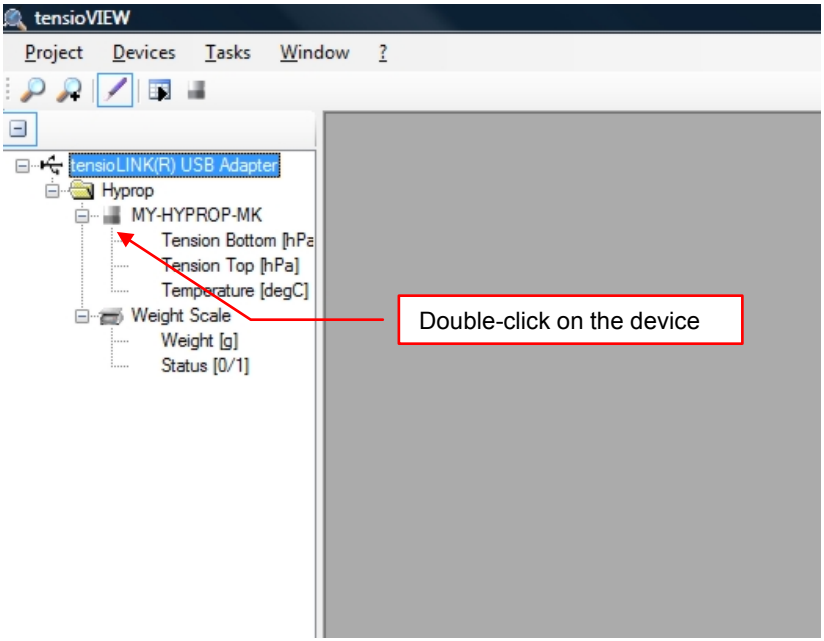


Figure 5-7

5.2.2 Device window

Detected devices will be displayed with their programmed names. Press the + symbol to see what readings parameter are available. Double-click on the name to open a menu window where all specifications and functions of this device are displayed. Depending on the type, different registries are available. The first shows an overview of the current settings and information about address number or error messages.

5.2.2.1 Properties

Gives an overview about the sensor head's basic properties and is only informative. You cannot edit the properties in this window.

5.2.2.2 Configuration of a device

Select the tab "Configuration" for viewing and changing the programmed settings of the device.

Depending on the authorization status, only parameters that can be edited are shown. To store a changed parameter in the device it has to be sent to the device by pressing the "Upload“ button. A message confirming the successful configuration will be displayed.
Configuration changes are effective immediately.

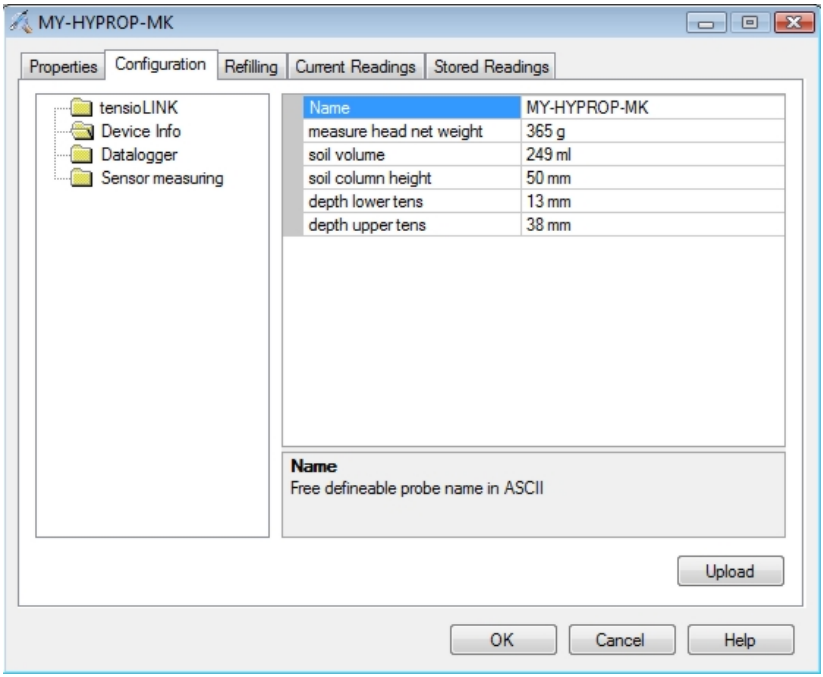


Figure 5-8

5.2.2.3 Configuration settings for HYPROP

Those settings which are editable only for *Power* users are marked with an asterisk *.
Parameters with related functions are bundled in one folder.

tensioLINK
Bus number
tensioLINK® bus number of the device
Sub address
tensioLINK® sub address of the device

Explanation:
tensioLINK® uses two types of address for each device, the bus address and the sub address. The reason for this is that is there might be sensors installed at the same spot, but with different measuring depths (for example multi-level probes). In this case, the sub address defines the depth starting with 1 for the highest sensor.
Furthermore, the sub address could be used to combine groups of sensors, for example of one measuring site.
In general the required identification for a device is always the bus number. If more than 32 devices are connected to the bus the sub address is counted up. The allowed numbers for the bus address are 1 to 32 and for the sub address 1 to 8.
The default value for both bus and sub address is 0. With more than one device connected individual addresses have to be declared.

Device Info
Name
Individually editable name of the Tensiometer in ASCII. Maximum length 12 digits
Measure head net weight
is the net weight of the sensor head incl. Tensiometer shafts and silicone disc.

* User rights are selected in the bottom status line. Select between „Public“ (limited rights) und „Power“ (extended rights). The software needs to be restarted when this setting is changed.

Soil volume
Volume of the soil sample in the sampling ring excluding the Tensiometer shafts' volume.
Soil column height
Height of the soil column in mm (height of sampling ring).
Depth lower tens
Protruding length of the lower shaft.
Depth upper tens
Protruding length of the upper shaft.

Data logger
Interval
the logging interval of the internal data logger
Overwrite old values
Overwrites old values (if you select „on") if the memory is full

Sensor measuring
Continuous measuring
Activate the quick updating of readings to receive the HYPROP readings instantly, for example during a refilling procedure. Measurements are taken in intervals of 50 ms. Note the rise in power consumption and that the reaction to serial commands might be slowed down. The setting "Measuring interval" is deactivated during this mode..
Measuring interval
This is the standard interval in which sensor measurements are refreshed and available on the analogue lines.
Enable filter
Activate the anti-flicker-filter. This avoids that the digit continuously jumps up and down. When activated the resolution is reduced for one digit.

5.2.3 Refilling window

This function is required when the HYPROP sensor head needs to be refilled or during assembly of sensor head and Tensiometer shafts (strictly recommended!!).

When the Tensiometer shafts are screwed back into the sensor unit the pressure reading must be checked at any time to avoid that excess pressure destroys the pressure transducer. Stop or slow down if the pressure rises to much. Please read the chapter 4.2 ”Refilling“ for more details.

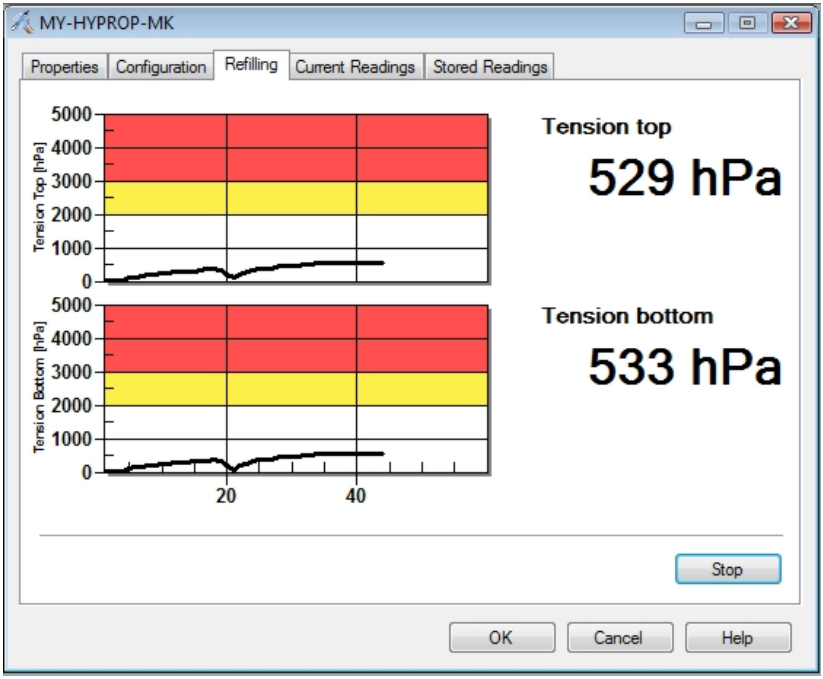


Figure 5-9

5.2.4 Current readings

In this window you can display current values of the Tension Bottom , Tension top and Temperature, depending on the Parameter Interval.

5.2.5 Stored readings

In this window you can download stored readings and delete stored readings, if logged data is available!

5.3 Add the scale

Before you can start a measuring campaign the scale needs to be added to the system. As scales have different specifications no automatic search is implemented in the program. Only scales supplied by UMS are pre-set.

There are two ways to add a new scale:

1. Click the right mouse button on HYPROP in the parent directory to open the “Add“ and “Add HYPROP device“ window. Click on „Add new Scales“.

2. Select the button in the menu <Devices> → <Add> → <Add new device“ ...

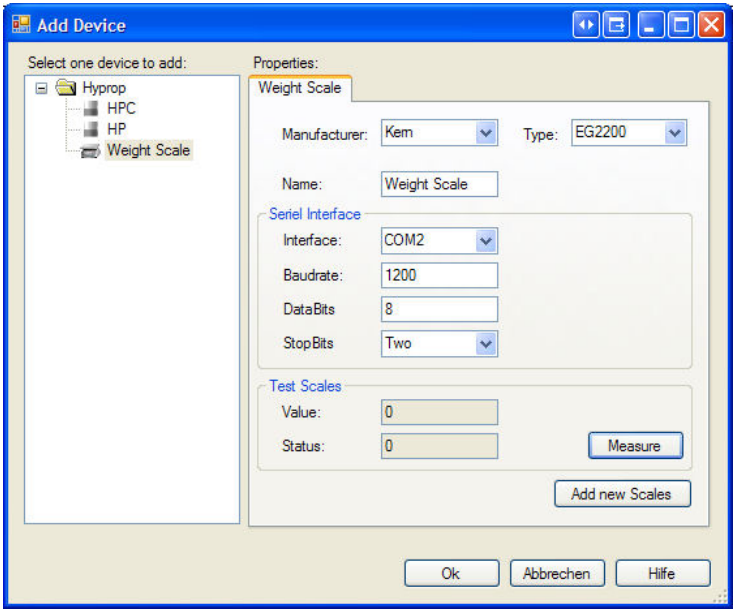


Figure 5-10

Select the scale type, for example “Kern EG2200“, the interface and the connection parameters. Then click on the Measure-Button. If a connection is established „zero“ is displayed for both status and reading. Click “OK“ to select the scale.

Now the new device is shown in the explorer window.

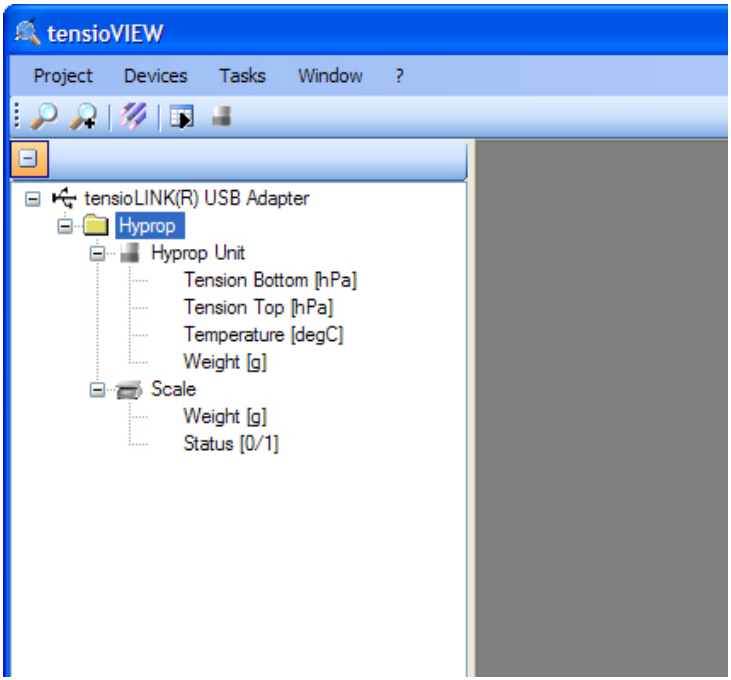


Figure 5-11

If you click on “Scale“ in the explorer window the current readings are shown.

6 Perform a measuring campaign

Definition: a measuring campaign comprises the set-up configuration, tension readings, weight readings and the evaluation of one HYPROP assembly or of all assemblies measured at the same time. This information is stored in one file for further use.

Familiarise yourself with the functions of tensioVIEW® before you start a measuring campaign.

- The starting conditions for a campaign are extremely important
- Always power a laptop with a mains power unit, not just only by battery.
- It is extremely important that the cable is not moved during a measurement campaign. Securely fix the cable as even a breeze can move a dangling cable causing variance in the measurement.
- Avoid leaving water drops on the fastener clips.

6.1 Starting conditions

The following conditions must be fulfilled before a measurement can be started:

1. The initial water content of the completely saturated sample is estimated. It can be calculated if the soil type is definitely known

2. The sample must be protected from direct sunlight, air currents or extreme temperature changes.

Figure 6-1

3. The scale should be placed on a vibration-free work table. The work table should not be used for other purposes during a HYPROP measurement.
4. During a single mode measurement we strictly recommend to fix the cable of the sensor unit.
5. The scale must be levelled out. Most scales have a bubble level.
6. Set the energy manager of your laptop to non-stop operation. Open the energy option manager and set „Power-down“ and „Stand-by“ to „Never“. If the laptop powers down or goes to the stand-by mode no readings are stored.

6.2 Measuring campaign window

There are two ways to open the measuring campaign window.

1. In the menu bar select <Tools> <HYPROP Measuring campaign>
2. Click this button:

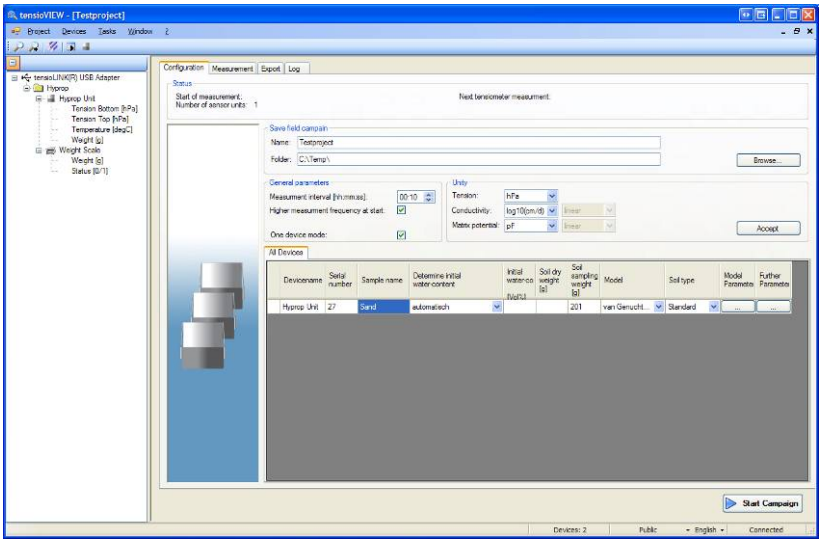
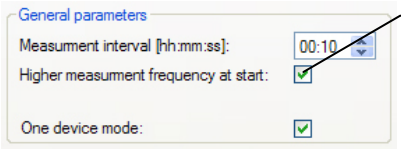


Figure 6-2

6.3 Configure the campaign

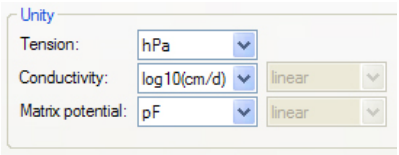
Open the measuring campaign window to configure the system.
Enter file name and directory where you want to store the measuring campaign:

Under <General parameters> enter the starting time of the campaign and the intervals when to weigh the samples (fig. below)). Select <Single device mode> if the campaign only includes one assembly.

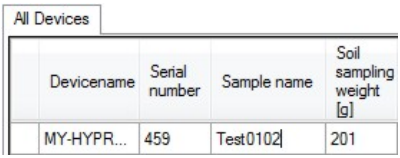


Higher frequency means: a measuring interval of 1 minute at the beginning of the measurement

In the units menu select the units for tension, conductivity and matric potential. Select either logarithmic or linear display.



In the <Devices> window the device name and serial number is displayed automatically.
Soil sampling ring weight (default 201g), and sample name need to be entered.



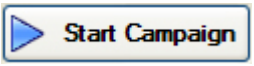
6.4 Perform the measurement

6.4.1 Single unit mode and multiplex device mode

In general there are two modes, the single unit mode and the multiplex devices mode. The following table shows the differences.

	Single unit mode	Multiplex device mode
Sensor unit	1	2-20
Symbol		
Weighing	remains on the scale continuously	you are asked to place each unit on the scale according to the measuring cycle
Measuring time	the selected measuring time is also the weighing interval	you set the time separately

6.4.2 Start of a measuring campaign



Click the button „Start Campaign“ to start the measuring campaign. The intervals entered in the configuration are assumed.

6.4.3 Constant starting conditions

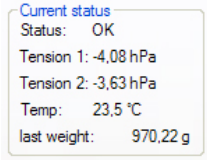
When you set the start line there must be constant starting conditions. This means that the tension values are constantly horizontal for a certain time period (preparation of the sample and hardware see chapter 6.1).

6.4.4 Start a spontaneou measurement

In the function window you can optionally click on <measuring> to start a measurement spontaneously (out of the constant measurement).

6.4.5 Current status of the measurement

In the left upper window (”Current status“) the current readings are displayed.



Anytime you can stop the campaign, change the interval or restart the campaign. The logging is continuously, starts and stops are marked with a dotted line in the graphs. The upper graph shows the tensions, the lower graph the weight.
The readings are displayed in a table on the right side of the graphs.

6.4.6 Measurements in the „Single device mode“

Select “Single device mode” under “General Parameters” in the configuration window. Set up the parameters as described in the previous chapters. In the single device mode only one measuring interval is entered which is used for both tension and temperature measurement.
Start the measuring campaign and do a zero set as described in chapter ”Zero Set”.

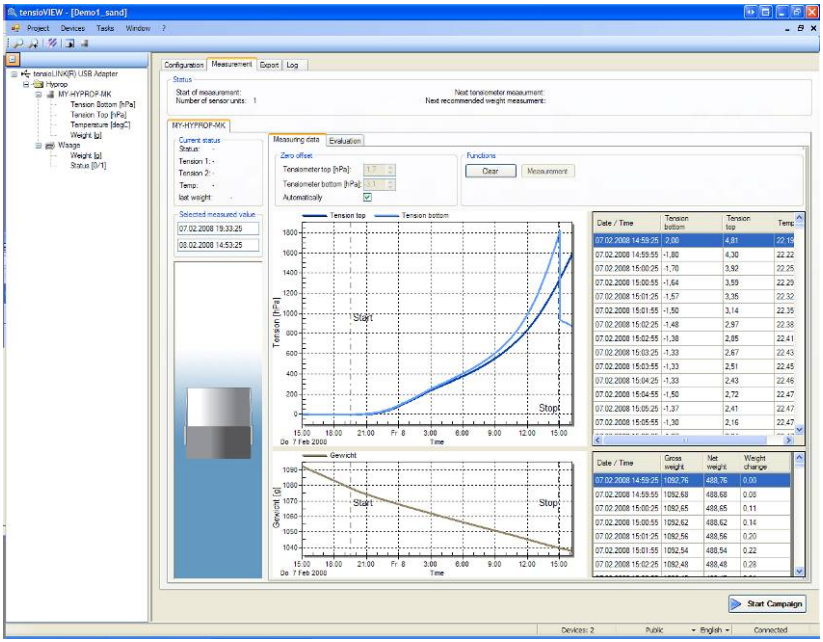


Figure 6-3

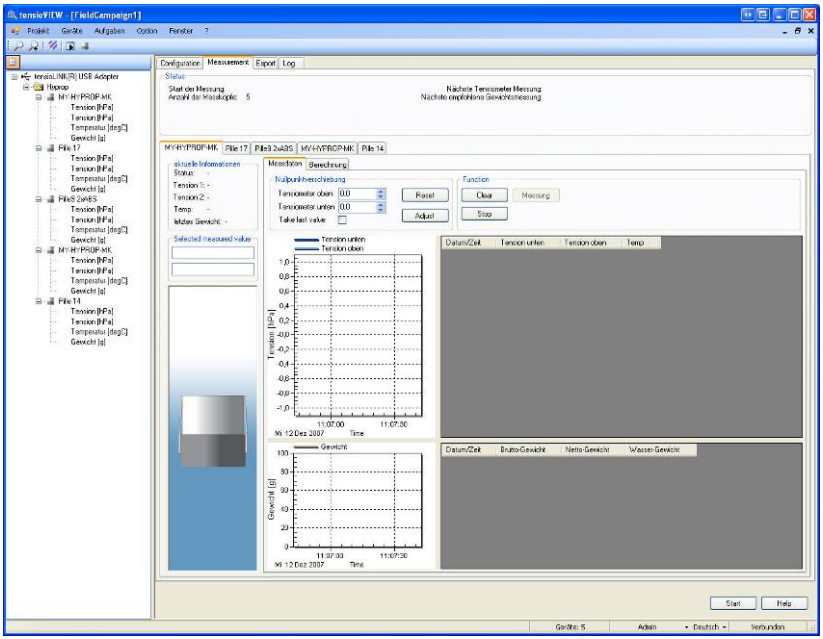


Figure 6-4

6.4.7 Multiplex devices mode

Connect all devices with tensioLINK® to the HYPROP main unit. Click on “Multiplex devices mode” to start a scan. Note that a different tensioLINK address is given to each device (see chapter ”Configuration Settings”).

Enter an interval for the Tensiometer measurements, for example 10 minutes.
The interval for weighing can be different than the one for tension measurement. As the weight of the sample changes slowly it is recommendable to choose a larger interval (depending on the soil type). For cohesive soils (clayey soil) we recommend an interval of 3 weight measurements per day. For less cohesive soils (sandy soil) 1 weight measurement per day is sufficient.
At the end of each interval you are asked to measure the samples. To do so unplug the LEMO plug from the sensor unit. The system

will automatically recognize which sample is put on the scale. The number of samples is limited to 20.
A new menu opens on the screen showing information about the status and the routine of the weighing.
Follow the given instructions (fig. 49).

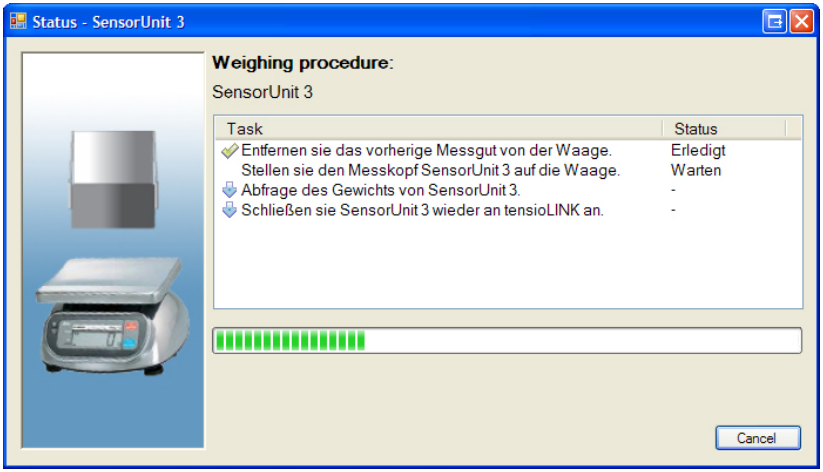


Figure 6-5

6.4.8 Interrupt a measuring campaign

A measurement can be interrupted temporarily as the readings are stored. Reload them with „Open project“ in the main tensioVIEW menu (also for example after a power breakdown).

6.5 Description of an ideal measured curve

Each measurement proceeds in 3 phases (provided that Tensiometers and sensor unit have an excellent filling).

Phase 1: Boiling retardation
The Tensiometer readings rise without flattening into the range of boiling retardation (beyond -85 kPa).
Phase 2: Consolidation
Water vapor accumulates. The Tensiometer reading abruptly drops down to the boiling point of approximately -85 kPa and remains constant at this level (dot and dash line in figure ....).
Phase 3: Air entry
The Tensiometer reading abruptly drops to 0 kPa as air enters the ceramic cup. The bubbling point of this ceramic is about -880 kPa (close to pF 4). This value is also used for the evaluation (see chapter “7 Evaluation”).

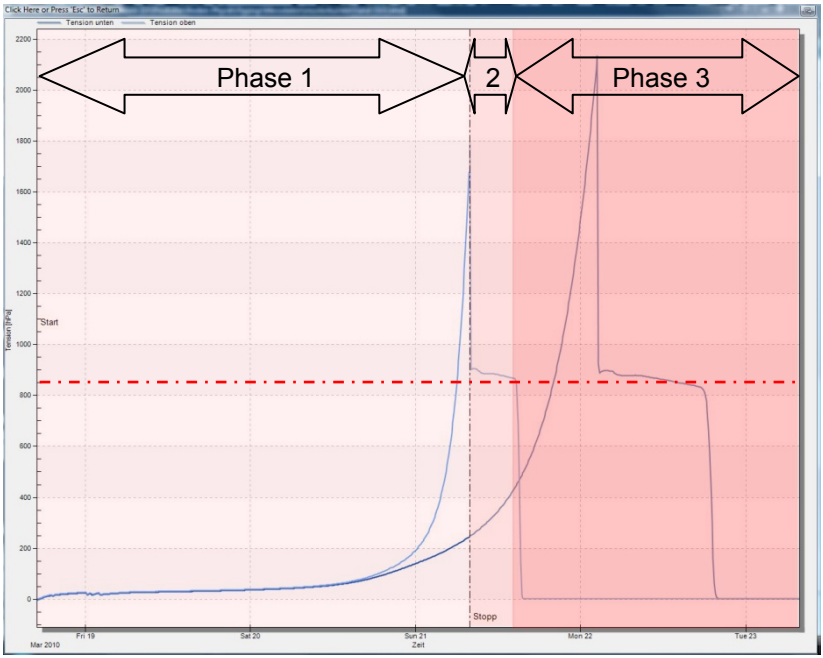


Figure 6-6: the different phases of the upper Tensiometer (left curve)

6.6 Conclusion of a measurement

A measurement campaign can be concluded if the 1st Tensiometer (T1) drops to 0 kPa (bubble point) and the 2nd Tensiometer is in Phase 1 (dash and dot line in Figure 6-7).

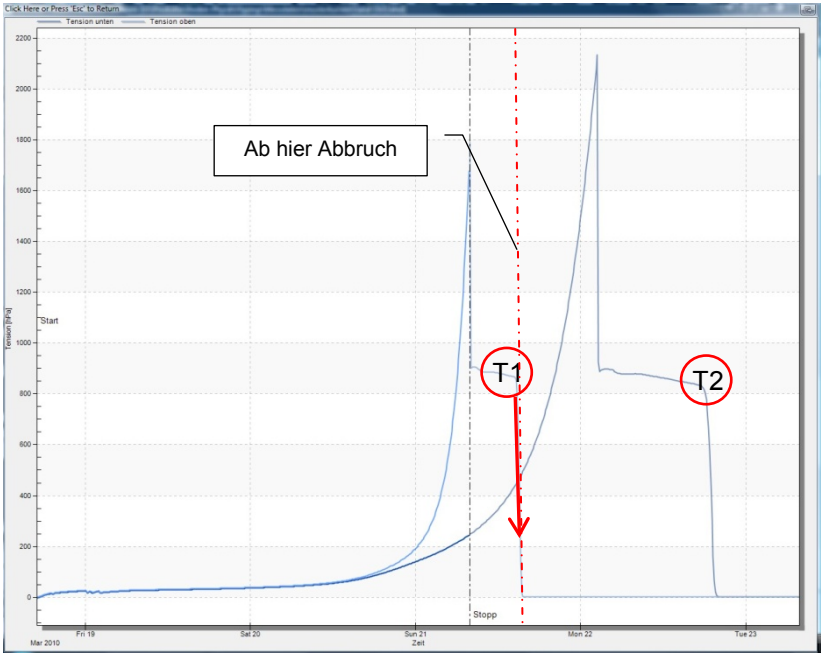


Figure 6-7

If the 1st Tensiometer (T1) drops to 0 kPa (air entry) and the 2nd Tensiometer is still in Phase 2 no averaging is possible. In this case you must wait until the 2nd Tensiometer (T2) reaches the bubble point. Then, the measurement can be concluded (see Figure 6-8).

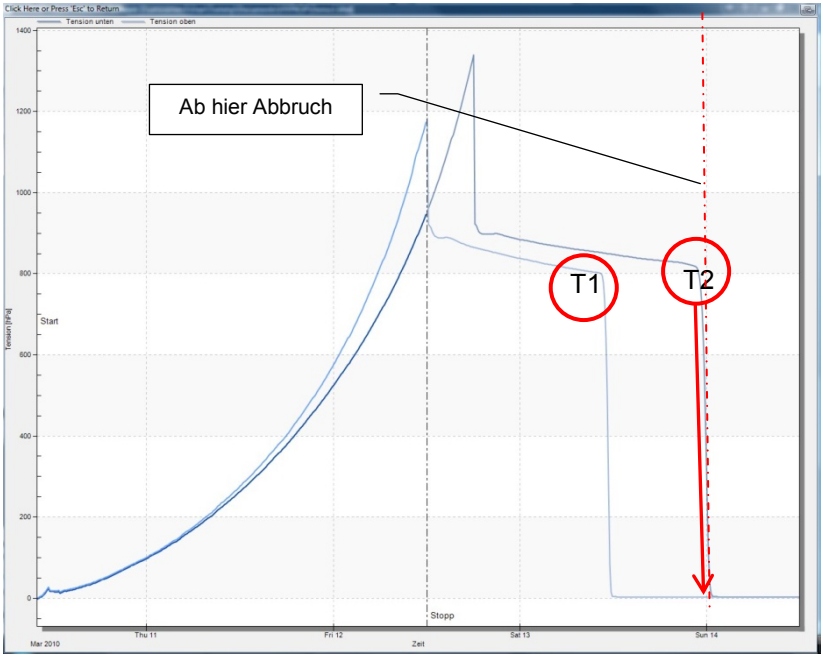


Figure 6-8

If an extraordinary error occurs the measurement can be stopped any time.

Exemplary measurements for various soils are shown in the appendix.

6.7 Remove the soil sample

1. Hold the whole assembly over a bowl or dish to assure that no soil material is lost.
2. Unlock the fastener clips. Gently pull on the soil sampling ring to take off the ring from the sensor head.

Figure 6-9

If the soil is too dry and if it is not possible to dismantle the HYPROP with the soil (e.g. clay) it is recommended to take the sample in water to get saturated over night.

3. Please clean the sample ring and the silicon disc above the bowl. It is more easy to take a brush (see pictures below)

Figure 6-11

Figure 6-10

4. Clean the sensorhead with water (wash bottle) and a dustfree tissue over the bowl.

5. In the end you should clean the sensor head and the tensiometer under running water (see picture below)

Figure 6-12

Please unscrew the both HYPROP shafts only when the sensor head is completely clean.

6.8 Dry weight

Empty the soil sample into a bowl with known weight. Dry it in a drying oven at 105°C for 24 hours and then weigh it again.

Figure 6-13

The „Soil dry weight“ will be used to calculate the actual water content and has to be entered later in the HYPROP FIT Software.

7 Evaluation

Evaluate a measurement with the HYPROP-FIT software.

To execute the evaluation in the correct order proceed through the menus „Information“, „Messung“, „Auswertung“, „Fitting“ and „Export“ step-by-step.

All options of the software as well as background information about evaluation and data fitting can be found in the extensive online manual of HYPROP-FIT (click on ‘Help’ in the status line).

8 Trouble shooting

Problem	Possible cause and solution
1. It is not possible to achieve a bubble free filling.	If the tip is completely dry just put the empty shaft in a beaker with deionised or distilled water overnight.
2. The Tensiometer readings only rise very slowly	a) Could depend on the soil type: for example sand has a poor conductivity. Thus, the curve of the readings will be flatter than for example in a clayey soil. b) The Tensiometer is not sufficiently filled and degassed (see 1) c) A leakage has occurred (see 3)
3. The Tensiometer reaches a maximum of -50 kPa, then the reading drops	The Tensiometer is not sufficiently filled and degassed (see 1). The shaft was not properly screwed onto the pressure body, and the O-ring is not tight. Reassemble the shaft.
4. The Tensiometer shows readings beyond vacuum (-100 kPa)	This is no error but a particular feature of the miniature Tensiometer. Due to boiling retardation it is possible that the T5 might reach values up to -140 kPa. Please check fig. 51 for this effect.
5. The curve cannot be fitted	a) Reset start and stop line as described in the chapter „End of the measuring campaign“. b) The curve progression is not consistently rising, eventually it is necessary to start a new measurement (causes see point 3)
6. The recording of readings has stopped	Check the USB connections In the power management menu of your PC or laptop disable the power down and select non-stop operation.
7. Tensiometer reach only -50 to -70 kPa, then readings drop slowly	The Tensiometer was not sufficiently filled. A bubble assembles inside the ceramic part

	and interrupts the water contact (see point 3)
8. At the beginning the lower Tensiometer surpasses the upper one which would indicate a negative conductivity	This is caused by inaccuracy of the sensors. Execute the “Zero offset“ to compensate the water column shift. Eventually set the starting point to a later point.
9.No sensor units are found in the multiplex device mode	Disconnect all sensor units. Connect just one unit and start a search in the single device mode. Check for each sensor unit that no address is given twice (see pages 42/43). In case, change the address as described in this manual. Sensor units can only be found if addresses are unique.

9 Service and maintenance

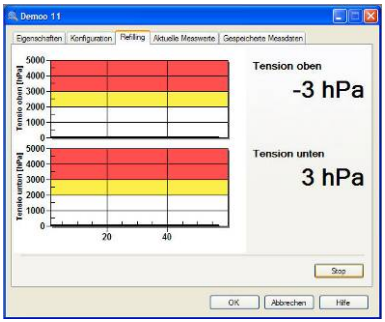
9.1 Check the HYPROP

1. First check if the Tensiometers of the HYPROP need to be refilled (recommended always at initial use and after a complete measurement campaign):
Connect the sensor unit with adapter cable and USB-converter to your PC and start tensioVIEW®.

2. Click on the magnifying glass symbol to search for devices.

Select the sensor unit you want to check.

3. Click on “Refilling” to open the “Refilling window”.



9.1.1 Check the Zero point

If the tips are moist both readings should be around 0 hPa (between -5 and + 5 hPa).
If you have not done the zero set (compensation of water column) the values are higher due to the shaft length.

9.1.2 Check the Response

Wrap a dry paper towel around one ceramic tip to create a momentary dry ceramic surface. Now create an air current around the ceramic cup, e. g. by waving a sheet of paper. The reading should rise to -80 kPa within seconds. If this is the case, the Tensiometer is filled correctly. If not, the Tensiometers needs to be refilled.
Do the same with the second tip.

9.1.3 Calibration

When delivered the HYPROP transducers (Tensiometers) are calibrated with an offset of 0 kPa (when in horizontal position) and a linear response. The offset of the pressure transducer has a minimal drift over the years. Therefore, we recommend to check the HYPROP sensor unit once a year and re-calibrate them every two years.
Return the HYPROP sensor unit to UMS for recalibration If necessary.

9.1.4 Check the Offset

Screw off the Tensiometer shafts. Carefully blow out remaining water from the shaft drillings. Connect the sensor unit to tensioVIEW® and continuously observe the readings.
Wait until the readings are stable. The readings should be between -0.2 kPa and +0.2 kPa. If the readings are beyond this range a re-calibration might be necessary.

9.2 Cleaning

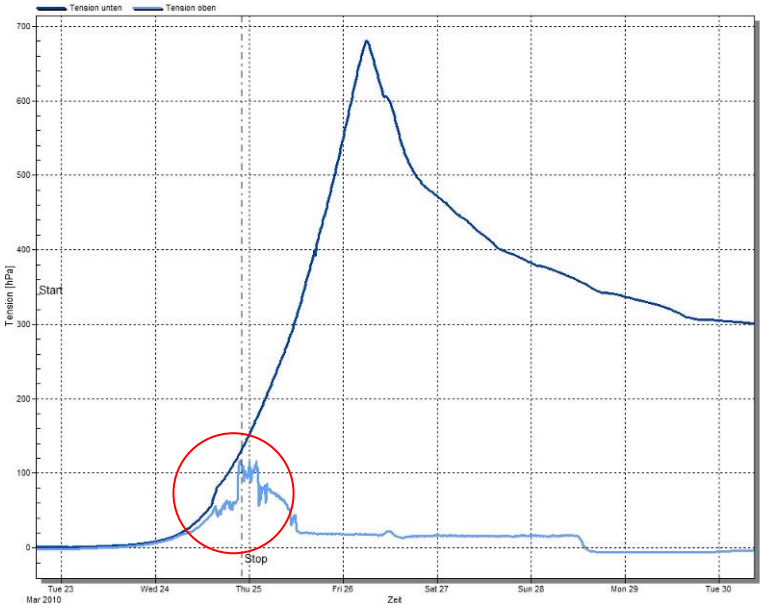
The sensor unit is rated IP65 and can be cleaned under running water, but pay attention that the cover of the plug connector is closed.
Clean ceramic and shaft only with a moist towel. If the ceramic is clogged it may be flushed with Rehalon®.
If the pores are clogged with clay particles saturate the ceramic and then polish the ceramic surface with a wetted, waterproof sandpaper (grain size 150...240).

9.3 Storage

If the HYPROP should not be used for a year or more empty shaft and sensor head to avoid algae growth. Store both in a dry place.

9.4 Change the O-ring on the HYPROP sensor unit

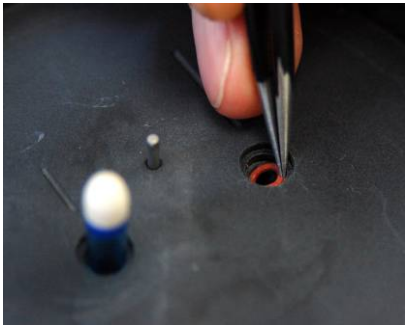
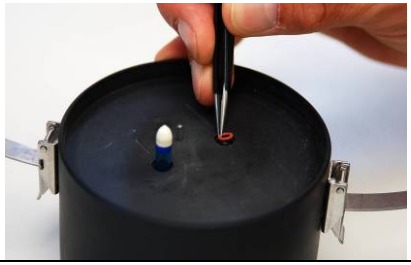
After many refilling procedures, but also if the O-ring is squeezed too hard with the shaft, the O-ring can be worn out, and is not sealing anymore.
You will notice this if the Tensiometer does not reach the boiling point anymore (i.e. close to 90 kPa), or the tension curve gets flat or drops abruptly at a point far below the boiling point (see figure below).



For replacing the O-ring a pair of fine pointed tweezers is required.

CAUTION: Do not insert the tip into the boring as you might punch the membrane of the pressure transducer..

How to proceed:

Pierce into the O-ring to pick it up and remove it. Spare O-rings can be find in the service case.	
Grab the replacement O-ring, but now not pierce it. Carefully insert the ring into the round groove inside the boring. If the ring does not slip into the groove carefully screw in the shaft to push the ring into its position.	

10 Theoretical basics

10.1 Evaporation method (overview)

In a soil sampling ring two Tensiometers, comparable to the T5 model, are installed in two depths (z_1 and z_2). The middle between the sensing tips of the Tensiometers is the centre of the soil sample. The sample is saturated, closed on the bottom and placed on a scale. The upper side of the sample is open to atmosphere so the soil moisture can evaporate. With the soil water tension [kPa] the average matric potential and the hydraulic gradient is calculated. The mass difference, measured by the scale, is used to calculate the volumetric water content and the water's flow rate.
A measuring campaign will last until one of the Tensiometers runs dry or the mass changes become marginal. Then, the remaining moisture content is determined by oven drying the sample at 105°C for 24 hours. With these values the retention curve and the unsaturated conductivity is extrapolated.

10.2 Discrete data for retention and conductivity relation

At different points of time t^i the water tensions h_1^i and h_2^i (in hPa) of both depths are measured as well as the weight of the sample (in grams ≅ cm^3). The analytic procedure is based on the assumption that water tension and water content distribute linear through the column, and that water tension and sample weight changes are linear between two evaluation points.

The initial water content is determined from the total loss of water (i. e. evaporation + water loss by oven drying).
The average water content $\overline{\theta}^i$, derived from initial water content and loss of weight, and the medial water tension $\overline{h}^i$ give a discrete value $\overline{\theta}^i(\overline{h}^i)$ of the retention function at any time t^i.

For the calculation of the conductivity function it is assumed that between two time points t^{i-1} and t^i the water flow through the cross

section situated exactly between both Tensiometers (and therefore exactly at column centre) is $q^i = ½\left(\Delta V^i / \Delta t^i A\right)$.

ΔV^i is the water loss in cm³ determined by weight changes, Δt^i is the interval between two evaluation points, and A the cross section area (in cm²) of the column.
The data for the hydraulic conductivity function are determined by inverting the Darcy-Equation:

$$K^i(\overline{\overline{h}}^i) = -\frac{q^i}{\Delta h^i / \Delta z + 1}.$$

$\overline{\overline{h}}^i = ¼\left(h_1^{i-1} + h_2^{i-1} + h_1^i + h_2^i\right)$ is the medial water tension between two evaluation points, with K^i as the related hydraulic conductivity (in cm h^{-1}).
$\Delta h^i = ½\left((h_2^{i-1} - h_1^{i-1}) + (h_2^i - h_1^i)\right)$ is the medial difference of the water tension between both Tensiometers, whereas $\Delta z = z_2 - z_1$ is the distance between both Tensiometers (in cm).

Unreliable $K(h)$ data sets close to saturation are filtered depending to the measuring accuracy of the Tensiometers.
To get a sufficient number of data points for the hydraulic function even with relatively long intervals, both the tension curve and the weight curve between two evaluation points are interpolated with hermitian splines (Peters and Durner, 2008). On this basis relatively short evaluation intervals are achieved.

10.3 Retention and conductivity functions

Normally hydraulic characteristics are described by parametric functions for $\theta(h)$ and $K(h)$.
With HYPROP three models can be chosen. These models can be adapted to measure data via a robust and non-linear optimizing procedure.

10.3.1 The van Genuchten/Mualem modell

With this model the effective saturation $S_e = (\theta - \theta_r)/(\theta_s - \theta_r)$ and the unsaturated conductivity K in relation to the matric potential h are predetermined by the following equation formula (van Genuchten, 1980):

$$S_e(h) = (1 + (\alpha|h|)^n)^{1/n-1}$$

$$K(h) = K_s(1 + (\alpha|h|)^n)^{\tau(1/n-1)}\left[1 - (\alpha|h|)^{n-1}\left[1 + (\alpha|h|)^n\right]^{1/n-1}\right]^2$$

Here the residual water content θ_r, the water content at saturation θ_s, the inverse value of the bubble point potential α [cm^{-1}] and the pore size distribution n [-] are the fitting parameters for the retention function. Furthermore, the tortuosity parameter τ [-] and the saturated conductivity K_s are fitted to get the conductivity function.

10.3.2 The bimodal van Genuchten/Mualem Model

This model suggested by Durner (1994) describes the retention and conductivity function by overlapping of two individual van Genuchten-functions (Priesack and Durner, 2006).

$$S_e(h) = \sum_{j=1}^{2} \omega_j (1 + (\alpha_j|h|)^{n_j})^{1/n_j - 1}$$

$$K(h) = K_s\left[\sum_{j=1}^{2} w_j\,[1 + (\alpha_j|h|)^{n_j}]^{1/n_j-1}\right]^{\tau}\left[\frac{\sum_{j=1}^{2} w_j\,\alpha_j\,\{1 - (\alpha_j|h|)^{n_j-1}[1 + (\alpha_j|h|)^{n_j}]^{1/n_j-1}\}}{\sum_{j=1}^{2} w_j\alpha_j}\right]^2,$$

The j are indexes for the parameters of each van Genuchten function, and w_j are the weights of both partial functions. The following restriction applies: $0 < w_j < 1$ and $\sum w_j = 1$.

10.3.3 The Brooks and Corey Model

In the Brooks & Corey model the retention and conductivity function are defined as (Brooks and Corey, 1964):

$$S_e(h) = \begin{cases} 1 & \text{for} \quad h \geq \alpha^{-1} \\ \left(\alpha|h|\right)^{-\lambda} & \text{for} \quad h < \alpha^{-1} \end{cases}$$

$$K(h) = \begin{cases} K_s & \text{for} \quad h \geq \alpha^{-1} \\ K_s \left[\left(\alpha|h|\right)^{-\lambda}\right]^{2/\lambda+\tau+2} & \text{for} \quad h < \alpha^{-1} \end{cases}$$

λ [-] and τ [-] are two fitting parameters which correspond to the pore size distribution, respectively with the tortuosity.

10.4 Optimization of the parameter

The $\theta(h)$- and $K(h)$ functions are adapted simultaneously to the data points. This is essential as distinct parameters (i. e. α and n at van Genuchten/Mualem) influence the shape of both functions. The adaption is accomplished by a non-linear regression under minimization of the sum of all assessed squares of the distance between data points and model forecast. However, the assumption that the water content is spread out linear over the column is not always fulfilled in coarse pored or structured soil. Therefore, the so called “integral fit” is applied for the adaption of the retention function to avoid an systematic error (Peters and Durner, 2006). For details of the fitting procedure and data assessment please refer to Peters and Durner (2007, 2008).

Please find a reference list in the appendix!

11 Additional notes

11.1 Extended measuring range

The extent of the measuring range of a Tensiometer is influenced by 3 factors:

1. The bubble point
2. The vapour pressure (boiling point)
3. The boiling retardation

11.1.1 The bubble point of the porous cup

The bubble point of a porous, hydrophilic structure is specified by the wetting angle and the pore size. The cups used for UMS Tensiometers have a bubble point far beyond the measuring range (8.8 bar). Therefore, the bubble point has no limiting influence.

11.1.2 The vapour pressure of water

At a temperature of 20°C the vapour pressure of water is 2.3 kPa against vacuum. With an atmospheric pressure of 100 kPa and at 20°C the water will start to boil, or vaporize, as soon as the pressure drops below 2.3 kPa against vacuum, i. e. 97.7 kPa pressure difference to an atmospheric pressure of 100 kPa - the Tensiometer drops out.
The measuring range (at 100 kPa/20°C) is limited to -97.7 kPa.

Atmospheric pressures announced by meteorological services are always related to sea level. Thus, the true pressure in a height of 500 meters over sea level is for example only 94.2 kPa although 100 kPa are announced. Then, the measuring range at this height (at 20°C) is even limited to -91.9 kPa.

If the soil gets drier than the maximum possible measuring range the reading will remain at this value and then drop gradually towards zero. If the soil gets as dry as the bubble point a spontaneous equalisation with the atmospheric pressure occurs. Air enters the cup and the reading will rapidly go to zero.

True pressure in heights over sea level at an atmospheric pressure related to sea level as published by meteorological services

Height over sea level (meter)	*Atmospheric pressure (kPa)*	*Max. measuring range at 20°C (kPa)*
0	101.3	-99.0
500	95.5	-93.2
1000	89.9	- 87.6
1500	84.6	- 82.3
2000	79.5	-77.2
2500	74.5	-72.2
3000	70.1	-67.8

11.1.3 Boiling retardation:

Water needs a nucleation site to boil. As our Tensiometers have polished surfaces and a gas-free filling the so called boiling retardation occurs – the Tensiometer keeps on measuring beyond the boiling point. To achieve this shafts and sensor unit must have an absolutely bubble free filling.
Some Tensiometer cups can go down to -250 kPa before they run dry, occasionally even a range of -450 kPa is achievable. As this is exceptional there is no guarantee for this measuring range.

For HYPROP measurements this means that a measuring campaign should be continued as long as the Tensiometers keep on functioning (unless the 8.8 bar range is irrelevant).

It is possible to get further information from the known bubble point which is 8.8 bar for the HYPROP cups. The moment the tension reading rapidly drops to zero the soil has a tension of -880 kPa (+/- 20 kPa). Therefore, it is recommendable to continue with the measurement until the tension reading is 0 kPa. (see publication: U. Schindler, JPNSS, The evaporation method - Extended measurement range of soil hydraulic properties using the air-entry pressure of the ceramic cup).

11.2 Vapour pressure influence on pF/WC

If the temperature of a soil with a constant water content rises from 20°C to 25°C the soil water tension is reduced by about 0,85 kPa due to the increased vapour pressure which antagonizes the water tension.

Temperature in °C	4	10	16	20	25	30	50	70
Pressure change per Kelvin in [hPa]	0,6	0,9	1,2	1,5	1,9	2,5	7,2	14

11.3 Osmotic effect

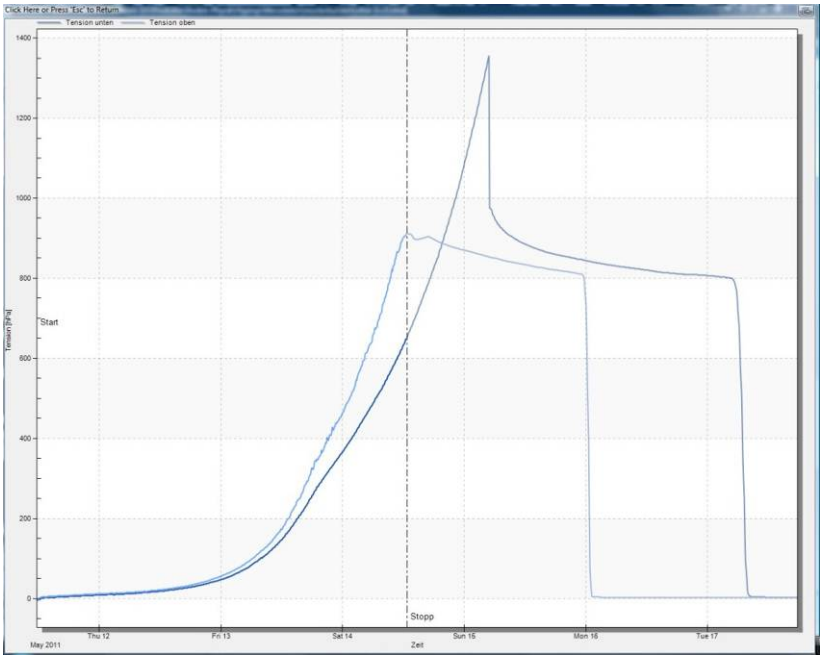
The ceramic has a pore size of r = 0,3 µm and therefore cannot block ions. Thus, an influence of osmosis on the measurements is negligible because ion concentration differences are equalized quickly. If the T5 cup is dipped into a saturated NaCl solution the reading will be 1 kPa for a short moment, then it will drop to 0 kPa again.

12 Appendix

12.1 Typical measurement curves

Following typical curves were kindly provided by Prof. Dr. Wolfgang Durner.

12.1.1 Sandy loam (Ls3)

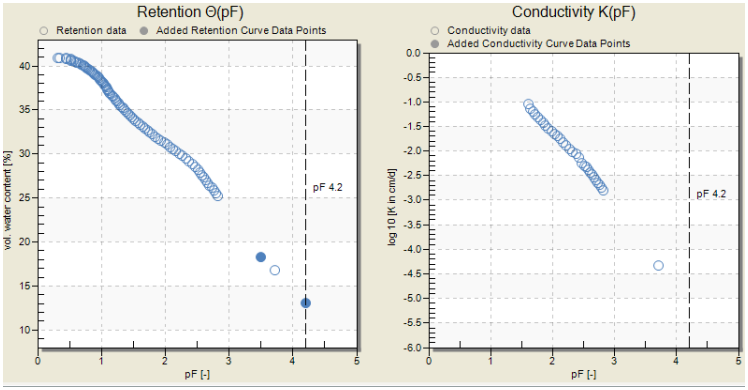


Site: Wolfenbüttel; Soil type: Slightly sandy loam. Ls3 (S 35%, U 48%, T 17%) ; Measurements in Winter 2011 "Geoökologische Labormethoden 2011", TU Braunschweig. Evaporation: 2,75 mm/d.
Temperatur: 21°C

Description of the measuring process

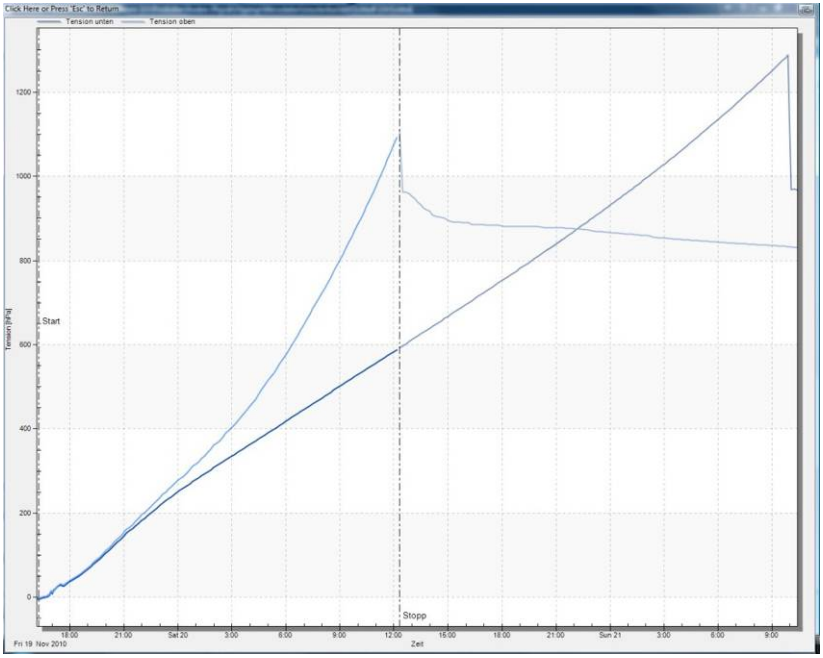
- The measurement process is typical of a clay with wide pore size distribution
- The water tensions rise almost two days continuously, but at a moderate slope. This reflects large pore fraction in clay of nearly 10%
- From about 50 hPa (pF 1.7), the tensiometers are far enough away to allow for the determination of hydraulic conductivities.
- After two days the tensiometers are now moving with a greater slope, but still rather weak curvature continues. The measurement limit is already reached a day later. This points out a limited and simultaneously diversified porosity.
- The spreading of tension values is moderate, which indicates a relatively high hydraulic conductivity in this area.
- The measurement is completed by the (almost too early) failure of the upper tensiometer after three days. At the time the sample is removed about 17% water.

Evaluation (with HYPROP FIT)



- The relatively uniform decrease in the water content with increasing pF and the drop of the relatively flat K data is characteristic of clays having a wide pore size distribution.
- The addition of the data point on the bubble point of the ceramic tip (power users only) fits very well with the independent, measured WP4 data points, and extends the range considerably.
- As a model to describe the data a bimodal function is needed.

12.1.2 Clayey silt (Ut3)



Site: Groß-Gleidingen bei Braunschweig; Soil type: clayey silt (S: 1%, U: 82%, T: 17%); Measurements: Praktikum Bodenphysik an der TU Braunschweig im Jahr 2010 (Gruppe 3). Evaporation: 14 mm/d using a fan. Temperature: 20°C

Description of the measuring process

- The measurement process is typical of a very fine grained substrate.
- The water tensions rise spontaneously immediately after the start of measurement, steeply and continuously. This reflects a very small proportion of coarse pores. pF 2.0 is reached (under the given conditions with fan) after a few hours. The loss of water to pF 2 is only about 4%.
- The "spikes" at the beginning of the measurements shows the discontinuous access of air penetrating into the soil.

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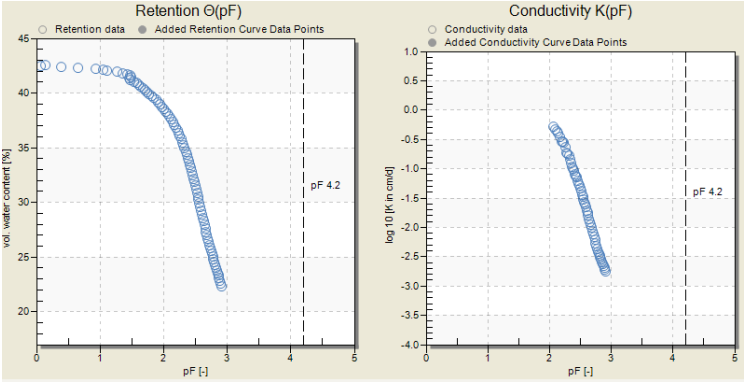
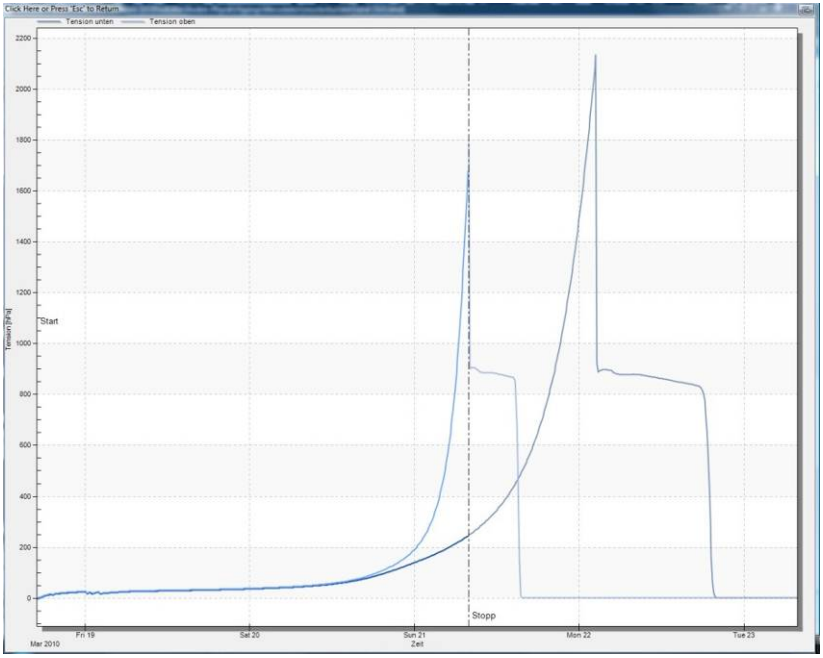
- From 100 hPa (pF 2.0), the first parallel tensiometers are far enough away to allow for the determination of hydraulic conductivities.
- Both tensiometer rise unabated with the passage of time and failled relatively soon. The clayey silt has few large middle pore, the finer middle pore region is in the time of failure still filled with water, the water content is therefore high.
- The spread of the tension values is moderate over the entire measuring process, which indicates a relatively high unsaturated conductivity.
- The measurement is completed due to the failure of the upper tensiometer after less than one day. At this time the sample has lost about 20% water.

Evaluation



- The initially flat and then getting steeper drop down in the water water content with increasing pF is characteristic of very fine-grained and clay substrates.
- The hydraulic conductivity at pF 2 is very high, but the curve then is even more steep than in the case of clay.
- The description of the data with models is not a problem, however in dry areas completely unsure. Suitable models are e.g. the van Genuchten model, or Kosugi model.

12.1.3 Slightly loamy Sand (Sl2)



Site: UMS-Fundus (siehe Probennummer).
Soil type: slightly loamy sand (S: 1%, U: 82%, T: 17%)
Messurements at UMS Soillab, Evaporation: 5.7 mm/d
Temperature: 23°C

Description of the measuring process

- The measurement process is typical of a sand with low fines
- The water tensions rise spontaneously immediately after the start of measurement, until they reach a level that corresponds to the bubble point. In this case it is about 30 cm (pF 1.5).
- Small "spikes" at the beginning of the measurements indicates that the air is not uniform, but in jerks occur in the system. This will be shown in the evaluation of the retention curve.
- The tensiometers run for a long time completely parallel, and differs only around a hydrostatic pressure difference of 2.5 hPa .
- Only after the main pores are beeing drained, the upper tensiometer value initially rises exponentially. The tensiometer failled very quickly, and the air entry point of the ceramic tip is reached shortly, while the lower tensiometer is still in the regular measuring range.
- The difference of the tensions is suitable only after reaching the exponential rise, that hydraulic conductivities can be calculated.
- The measurement is completed due to the failure of the upper tensiometer after a lost of of nearly 30% water.

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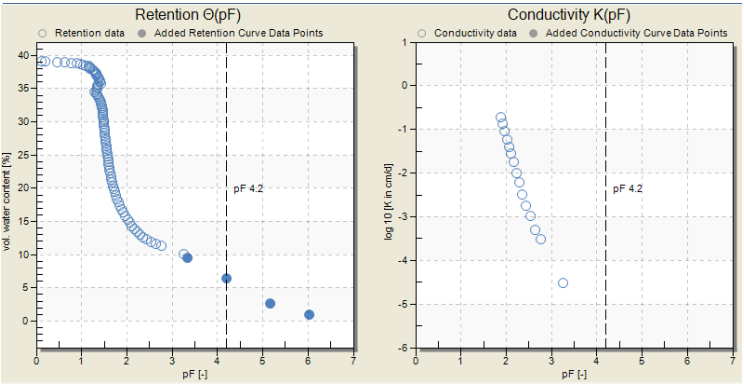
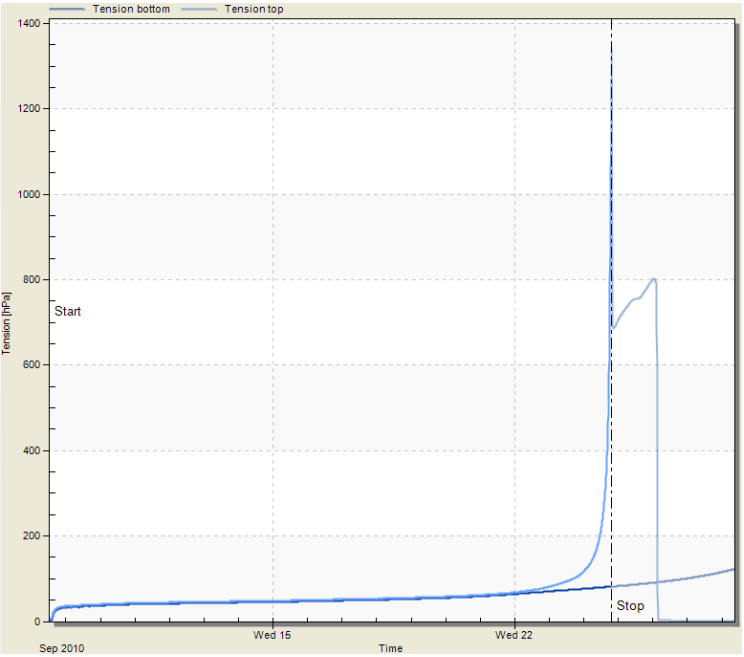
Evaluation



The additional data in the dry zone were by Lisa Heise within their thesis at TU Braunschweig / UMS Munich measured using a device made by Decagon (WP4C. They are documented in Heise's thesis (http://www.soil.tu-bs.de/mitarbeiter/dipl_detail.php? id=78).

- The pronounced air entry point and the steep drop down of the retention curve after reaching the air entry point is characteristic of the sand.
- The hydraulic conductivity can be determined only from 2.0 pF, and then drops down steeply.
- Suitable models for data description are the Fayer-Simmons model, or the bimodal model to describe the subsequent drop of the retention values towards dehydration.

12.1.4 Reiner Fein- bis Mittelsand (Ss)



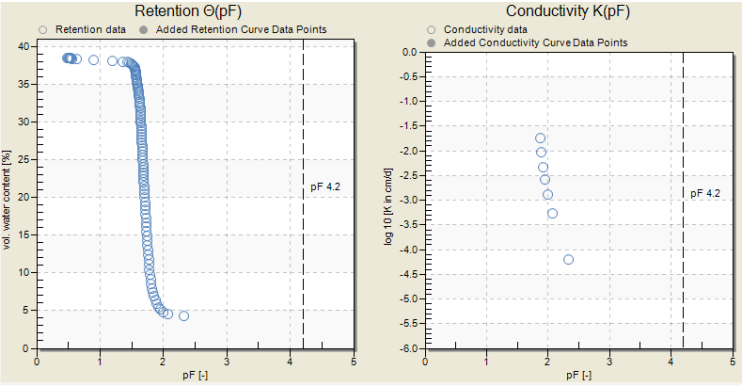
Material: packed quartz sand particle size: 0.1 bis 0.3 mm
Soil type: sandy sand (S: 100%, U: 0%, T: 0%)
Site: Bodenphysikalisches Labor, TU Braunschweig
Evaporation: 1.4 mm/d
Temperature: 22°C

Description of the measuring process

- The measurement process is typical of a sand with narrow particle size distribution and without fines
- The tension rise spontaneously immediately after the start of measurement, until they reach a level that corresponds to the bubble point. In this case it is about 50 cm (pF 1.7).
- The tensiometers run for a long time completely parallel, and differs only around a hydrostatic pressure difference of 2.5 hPa.

- After draining the main pore portion the tensiometer value of the upper tensiometer rises extremely steep. The failure of the tensiometer is now very quick.
- The lower tensiometer is at the end of the measurement still completely unaffected by the extreme dehydration front, the difference of water tensions is very high.
- Hydraulic conductivities can be calculated only for a short period of time.
- The measurement is completed due to the failure of the upper tensiometer after removal of 35% water

Evaluation



- The very sharply defined bubble point and the extremely steep drop in the retention curve after reaching the air entry point is characteristic of pure sand with a uniform grain size.
- The hydraulic conductivity can be determined only within a very narrow tension intervall, and drops down very steeply.
- Suitable models are the data description Brooks Corey model, the van Genuchten model of free parameter m or the-Simmons Fayer model.

12.2 Typical results for different soil

Typical results for different soils after data export.

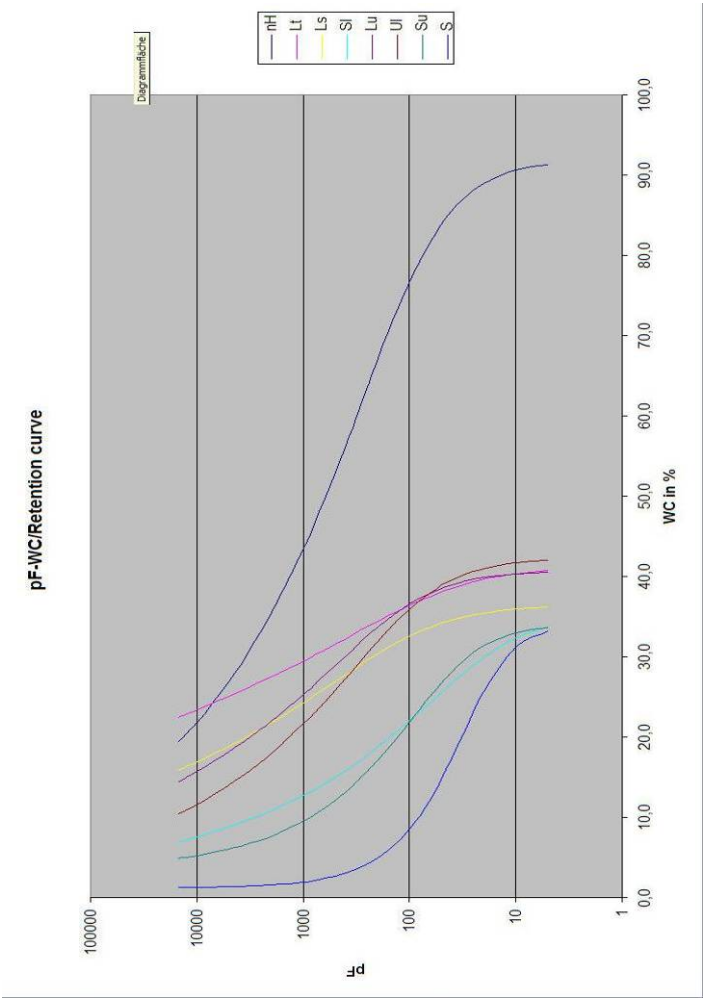


Fig..52 : pF-WC curves (kindly supported by Dr. Uwe Schindler, ZALF Müncheberg)

12.3 Parameter list

12.3.1 Input

Geometric variables:	
V [cm] FLOAT	Soil sample volume
z_1 [cm] FLOAT	Height of Tensiometer 1 (over bottom of soil sample)
z_2 [cm] FLOAT	Height of Tensiometer 2 (over bottom of soil sample)
L [cm] FLOAT	Length of the soil sample
For generating data points:	
INTERPOL INTEGER	Type of data interpolation: 0: polynomial; 1: partially linear; 2: hermitical spline)
nbt INTEGER	Max. number of data points for the hydraulic function
OPTIMI LOGICAL	If TRUE, then optimization is executed, if FALSE only data points are generated
NDEG INTEGER	If INTERPOL = 0, then order of the polynomial
Measuring inaccuracy:	
σ_h [cm] FLOAT	Measuring error of the potential (standard deviation)
σ_w [g] FLOAT	Measuring error of the weight (standard deviation)
For parameter estimation:	
CODE INTEGER	Type of model 10: van Genuchten/Mualem 11: van Genuchten/Mualem bimodal 20: Brooks/Corey)
INIT FLOAT (vector)	Start up estimation of parameters, respectively the fix value if parameter x should not be estimated
OPTP LOGICAL (vector)	Indicator if parameter x should be optimized or not
IN_MAXOPTIT INTEGER	Obsolete! Must always be 1!
W_DEV FLOAT	Obsolete! Not condsidered
IN_WEIGHTFLAG LOGICAL	If TRUE then both hydraulic functions are automatically rated as described in chapter „Fit of parametric expressions to the θ(h) and K(h) data“ (JH-Paper: Simplified evaporation method for determining soil hydraulic properties A. Peters *, W. Durner).

	Otherwise w_θ and w_k in equation (3) can be rated manually with parameters w_θ and w_k.
w_θ FLOAT	Rating for the retention data (only considered if IN_WEIGHTFLAG = FALSE.)
wk FLOAT	Rating of the conductivity data (only considered if IN_WEIGHTFLAG = FALSE.)

The parameter collections “Control parameters for Levenberg-Marquardt algorithm“, “Control parameters for SCEUA algorithm“ and “LM-Floatpar” should NOT show up. These are special parameters for setting the optimization algorithm.

12.3.2 Output

$RMSE_\theta$ FLOAT	Root mean squared error of the retention function adaptation
$RMSE_K$ FLOAT	Root mean squared error of the conductivity function adaption

$$\mathrm{RMSE}_\theta = \sqrt{\frac{1}{n_p}\sum_{i=1}^{n_p}(\overline{\theta}_i - \hat{\theta}_i)^2}$$

$$\mathrm{RMSE}_K = \sqrt{\frac{1}{n_p}\sum_{i=1}^{n_p}(\overline{K}_i - \hat{K}_i)^2},$$

with $\overline{\theta}_i$ and $\overline{K}_i$, resp. $\hat{\theta}_i$ and $\hat{K}_i$ being the measured resp. predicted values for the retention and conductivity function. n_p is the number of data points.

12.3.3 Parameter listing and describtion of the .csv table:

Tabelle	*Parameter*	*Einheit*	*Beschreibung*
_Weight.csv	ValueGross	g	Cross weight
	ValueNet	g	Net weight of the sample
	ValueDiff	g	Weight loss
_Tension.csv	Tension1	hPa/kPa	Top Tensiometer
	Tension2	hPa/kPa	Bottom Tensiometer
	Temp	hPa/kPa	Temperature
_STATVEC.csv	RMSETH		Root mean squared error of the function of Retentionscurve
	RMSELOGK		Root mean squared error of the function of conductivity curve
_PARVEC.csv			Fittingparameter, please look at chapter HYPROP Theory
_HYDFUNC.csv	pF		pF- Value
	Theta	m^3/m^3	Water content
	K	cm/d	Hydraulic conductivity
_EVATH.csv	PMEAN	hPa/kPa	Medium water potential
	WCMEAN	m^3/m^3	Medium water content
_EVAK.csv	PMEAN	hPa/kPa	Medium water potential
	Cond	cm/d	Hydraulic conductivity

12.4 Units for soil water and matric potentials

	pF	hPa	kPa=J/kg	Mpa	bar	psi	%rF
	1	-10	-1	-0,001	-0,01	-0,1450	99,9993
	2,01	-100	-10	-0,01	-0,1	-1,4504	99,9926
FK field capacitiy	2.53	-330	-33	-0,033	-0,33	-4,9145	99,9756
Tensiometer ranges*	2.93	-851	-85,1	-0,085	-0,85	-12,345	
	3	-1.000	-100	-0,1	-1	-14,504	99,9261
	4	-10.000	-1.000	-1	-10	-145,04	99,2638
Permanent wilting point	4.18	-15.136	-1.513	-1.5	-15	-219,52	98,8977
	5	-100.000	-10.000	-10	-1 00	-1.450,4	92,8772
Air-dry**	6	-1.000.000	-100.000	-100	-1 000	-14.504	47,7632
Oven-dry	7	-10.000.000	-1.000.000	-1.000	-10 000	-145.038	0,0618

* standard measuring range of Tensiometers
** depends on air humidity

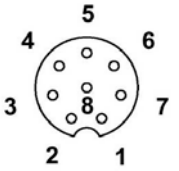
Note: 0,981 kPa corresponds to 10 cm water column

12.5 Technical specifications

Material and dimensions	
Sensor unit housing Dimensions	Fibre-glass reinforced Polyamide Height 60 mm, ∅ 80 mm
Tensiometer shafts	
Ceramic Shaft material Total length	Al_2O_3 sinter, bubble point > 200 kPa; ∅ 5 mm Acrylic glass; ∅ 5 mm Lower: 25 mm Upper: 50 mm
Cable	
Length	1,5 m
Plug	4-pin LEMO
Measuring range	
Pressure transducer	-300 kPa ... +300 kPa (electronically) -85 kPa ... +300 kPa (physical)
Water tension	-85 (-450)kPa 0 kPa depends on refilling quality
Temperature	-30 °C ... +70 °C
Accuracy	
Pressure Temperature	±1,5 hPa / d = 0,05 hPa ±0,2 K (-10...+30 °C) / d = 0,01 K
Power supply	
Power Vin	6 ... 10 V DC
Current consumption	6 mA nominal, (max. 15 mA)
Chemical resistivity	
PH-range	pH 3 ... pH 10
Contact media	Limited for media that not affects silicon, fluorsilicone, EPDM, PMMA or polyetherimide
Protection	
Housing with plug covered	IP 65 (splash water proofed)
Sensor units	
Max. number of sensor units which are supported by tensioLINK	20

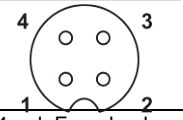
12.5.1 Wiring configuration

USB converter		
Signal	**Pin**	**Function**
Vout	1	Supply +7 +10 VDC
GND	2	Supply minus
n.c.	3	-
n.c.	4	-
n.c.	5	-
RS485-A	6	RS485-A twin
RS485-B	7	RS485-B twin
n.c.	8	-



8-pin female plug

Connection cable USB Converter → T-junction		
Signal	**Pin**	**Function**
Vout	1	Supply +6 +10 VDC
RS485-A	2	RS485-A twin
GND	3	Supply minus
RS485-B	4	RS485-B twin



4 pol. Female plug

12.6 Accessories

12.6.1 HYPROP extension and Accessories

UMS art. no.:	Describtion:
HYPROP-E	Set consisting of: Sensor unit 2 Tensiometer shafts T-piece junction plug Connection cable with LEMO plug Note: a sampling ring is not included, please order separately.
SZ250	Soil sampling ring, vol. 250 ml, stainless steel, outer diam. 84 mm, inner diam. 80 mm, height 50 mm, incl. 2 caps
HYPROP-TK	Tensiometer shaft set: pair of Tensiometer shafts, one each with length: 1x 50 mm 1x 25 mm
SZA250	Hammering holder for sampling rings 250 ml, length 300 mm, weight 0,6 kg, handle with hand protection, for rings with outer diam. 84 mm

HYPROP-Sat 	HYPROP Saturation bowl
HYPROP-SV	HYPROP – vacuum syringe
HYPROP-SW	HYPROP – water syringe
HYPROP-Scale 	HYPROP - Scale
HYPROP-train	HYPROP training Incl. training material (ca 4 h)

Refillstation and Accessories

UMS art. no.:	Describtion:
	HYPROP – refill unit (connection to external pump) incl. vacuum bottle, manometer, Absperrhähne (available end of 2011)
	HYPROP -vacuumpump (available end of 2011)

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